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New York State Technology Enterprise Corporation

presents its

Options for a Public Safety Wireless Communications System: Synthesis and Evaluation Report

for the

Tompkins County Radio System Project

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Version 2

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1. Overview

NYSTEC reviewed different radio communications technologies and evaluated their applicability for Tompkins County public-safety (law enforcement, fire, EMS) mobile wireless communications requirements.

At a high level, there are two major technology classes — terrestrial based or "off planet" — to provide mobile wireless communications. Terrestrial-based technologies include cellular telephony, PCS (personal communications services), and land-mobile radio (LMR). These require a network of interconnected sites, often towers, which provide the air interface with the users' radios. "Off Planet" technologies include satellite services. The satellites are the equivalent of sites in the terrestrial model, though there are ground support centers also.

The potential technologies then need to be compared against the communications requirements for public safety. These can be summarized as:

- Point-to-Multipoint calls and user groups (Dispatch operations),
- Fast call throughput (Push-to-Talk, low connection time),
- Ubiquitous coverage (ability to communicate all over),
- Priority calling (ability to manage communications loading of the network),
- Call preemption (ability to interrupt a transmission for emergencies),
- Wireless regulatory constraints (RF transmission is regulated and requires licensing from the federal government), and
- Mainly used by professionals, public-safety/public-service personnel, as opposed to civilians/consumers.

The only technology that can satisfy all those requirements is LMR. With LMR, however, there are many different factors and choices that need to be evaluated:

- Frequency band (Low Band, High Band, UHF, 700 MHz, 800 MHz),
- Trunking vs. conventional,
- Multicast vs. simulcast,
- Digital vs. analog,
- Access method - FDMA (Frequency Division Multiple Access) vs. TDMA (Time Division Multiple Access),
- Land-Mobile Radio Architectural Topologies - Project 25, TETRA (and proprietary ones), and
- Siting, including towers, shelters, equipment, power, and environmental impact.

NYSTEC evaluated specific LMR configurations:

- Enhancement of Current Land-Mobile Radio System,
- Trunked, VHF Land-Mobile Radio System,

- Trunked, Digital, 800-MHz Land-Mobile Radio Network, and
- The New York Statewide Wireless Network (SWN).

The finding of these evaluations is that a trunked, digital, 800-MHz LMR network would best meet the requirements. Because SWN will be a similar network, NYSTEC recommends that Tompkins County plan to become part of it. The SWN project currently is in a dynamic state; however, NYSTEC recommends that the County continue with its acquisition process for its own system up through evaluating proposals from vendors. At that time, the County can evaluate the viability and status of SWN relative to the timetable the County wants to follow. There are costs for the County associated with developing a Request for Proposal (RFP) and evaluating vendor proposals, while the State continues with progression of the SWN project. This parallel approach, however, reduces the risk to the County. Should SWN turn out to be not viable for meeting the County's needs, the County has not lost valuable time in getting a system procured and implemented. If the SWN project and its timetable clearly becomes suitable for the County, the RFP will serve to define explicitly to the SWN project the requirements of the County, thus better assuring that the SWN system will meet the County's needs.

2. Wide-Area Wireless Mobile Technology

Numerous sectors of society use two-way radio. Almost any one with a desire to exchange information will utilize it in one form or another. The use can be as basic as that of a security guard in a department store communicating with someone monitoring video surveillance, or as elaborate as a county digital trunked state-of-the-art radio system. This section discusses the basic concept of wireless technology, with an emphasis on its use in the public-safety sector. Examples of past and present radio systems provide the starting point.

This section discusses major aspects of a land-mobile radio (LMR) system and how they fit and how they work in the overall system engineering. This is done to provide Tompkins County with some idea of what goes into a LMR system. Included in this section are a number of critical functional infrastructure techniques that will be part of future recommendations to the County. These functional infrastructure techniques detailed here for the County's future considerations are:

- Radio Frequencies,
- Conventional Radio Systems,
- Digital Voice, Data, and Encryption Communications,
- Voting Systems,
- Trunked Radio Systems,
- Simulcasting, and
- Microwave Technology.

Detail is presented — especially for the applications of digital trunking, simulcasting, and microwave transport[1] overlay of a system. These infrastructure techniques bring to Tompkins County a number of communications options that are critical to solving operational and safety issues that exist. Further, this section includes a high-level discussion of the important requirements of public-safety communications systems.

2.1 Radio Frequencies

In Figure 1, the frequency bands used by LMRs are shown in the context of the entire electromagnetic spectrum. The figure also shows some of the types of users currently operating in the various frequency bands. Radio frequency bands are discussed in this section.

[1] Microwave transport overlay: microwave technology acts as the media that links radio sites. This is an information link or layer within the overall system.

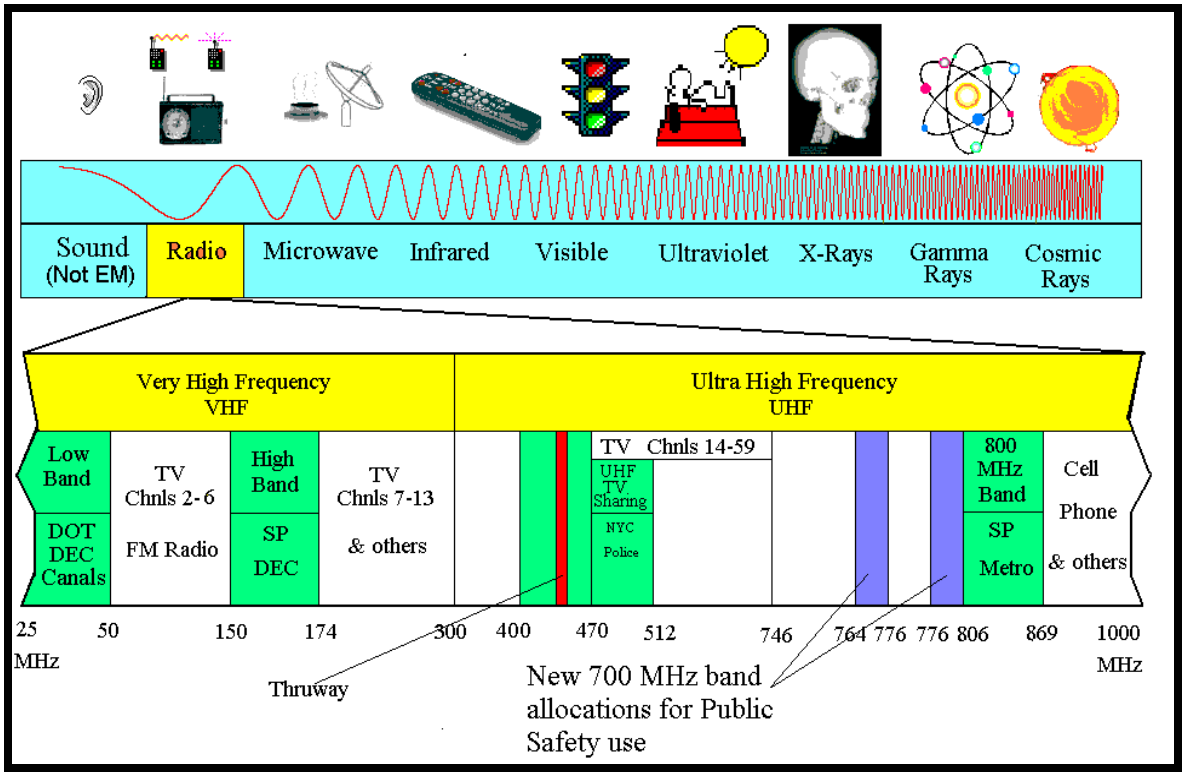

Figure 1, Electromagnetic Spectrum and Radio Frequencies

Based on Figure 1, Table 1 shows frequency bands for public safety. Note that these are only the frequencies used for over-the-air communications between the sites and the users' radios. Communications between the sites themselves, which can be done with microwave radios, fiber optics, or coaxial cable (telephone lines) is part of the interconnect transport infrastructure and is discussed later in the report.

Table 1, Radio Sub-Band Designation for Land-Mobile Radio

Band	Frequency Range
Low-Band VHF	25-50 MHz
High-Band VHF	150-174 MHz
220 MHz	220-225 MHz
Federal Band UHF	406-420 MHz
Non-Federal UHF	450-470 MHz
UHF TV Sharing	470-512 MHz
700 MHz	764-806 MHz
800 MHz	806-869 MHz

2.1.1 Advantages and Disadvantages of Low-Band LMR

A number of issues related to low-band VHF operation should be considered when deciding on a product. The frequency range (30-50 MHz) at which VHF equipment operates has both advantages and disadvantages. Some advantages include:

- High-power radio equipment availability and

- Good wide-area outdoor coverage.

In general, propagation loss increases with frequency near the earth or, in other words, over geophysical terrain. Using the formula for calculating free-space path loss (FSPL), over varying distances and frequencies, a family of curves can be generated[2]. Figure 2, which covers frequencies typically used for mobile radio communications, shows that free-space loss increases with distance.

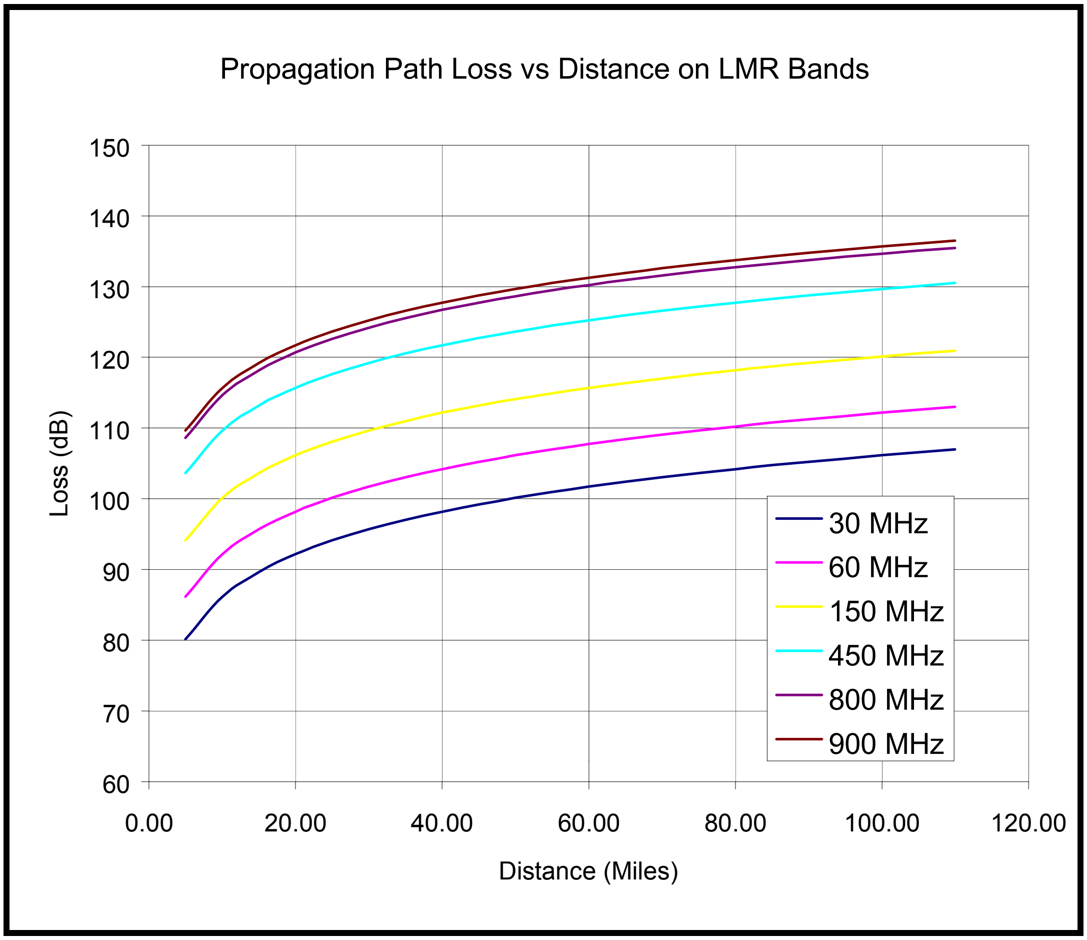

Figure 2, Plot of Propagation Loss vs. Distance Across the LMR Frequency Bands

Over the past decade, LMR equipment parameters have been migrating from low-band VHF to high-band VHF and to 800-MHz frequencies. Due to the exodus from low band VHF, that spectral region is used less and, hence, may be more available. For subscriber equipment operating in the low-band region, output power of 100 watts from mobiles is quite typical. Transmission ranges can be substantial; thus, the good propagation characteristics at these frequencies usually require less siting.

There are serious disadvantages to low-band VHF operation. The diffraction of low-band waves around metal beams and reinforcement bars used in building construction is very poor because

[2] Freespace Path Loss (dB)=36.6+20Log(Distance in miles)+20Log(Frequency in MHz).

the wavelengths of low-band VHF are physically very long. As a consequence, in-building propagation (particularly in commercial buildings) is very poor.

Tompkins County, like many counties, years ago first started using low-band paging to alert volunteer firefighters instead of depending on fire-station whistles to summon personnel to a fire. This worked well when many of that volunteer force lived and worked in rural areas where they were out of doors or inside wood frame structures. Today, with the advent of a more mobile society, along with better highways, that same volunteer fire-fighting force works further away, often in urban centers inside offices and industrial buildings. Low-band paging in many public-safety applications (Tompkins County is no exception) was not designed to meet the challenges of in-building coverage. These same industrial buildings, because of their metal and concrete composition, greatly challenge the physics of low-band paging.

Radio communications above 30 MHz utilize ground-wave propagation, which implies a range dictated by the line-of-sight distance to a receiver. Depending upon the particular frequency, ground-wave propagation distance also depends on factors such as terrain, manmade obstructions, and foliage.

Frequencies as high as 50 MHz can be subject to the same propagation phenomena as frequencies at the upper end of the high frequency (HF) spectrum around 30 MHz. This particular propagation phenomenon is due to the sunspot cycle and aurora borealis. Sunspots are cyclic in nature and have a cycle duration of eleven years. Data on sunspot intensity dates back to the late 1700s, as shown in Figure 3.[3] The present cycle, which began in the late 1990s, is referred to as sunspot cycle number 23. Figure 4[4] shows the measured sunspot activity at the end of cycle number 22, and the upper and lower bounds for the predicted sunspot numbers and their estimated values for cycle number 23. In his predictions, Hathaway[5] combined three sunspot-prediction methods using smoothed international Sunspot number data. Cycle number 23 is expected to peak in the fall of 2000 and to not reach its minimum until sometime in 2006.

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[3] Sunspot Index Data Center, Royal Observatory of Belgium, http://www.oma.be/KSB-ORB/SIDC/.

[4] Sunspot cycle predictions by David Hathaway, National Aeronautics and Space Administration (NASA), Marshall Spaceflight Center, Huntsville AL, http://science.msfc.nasa.gov/ssl/pad/solar/predict.htm .

[5] Ibid.

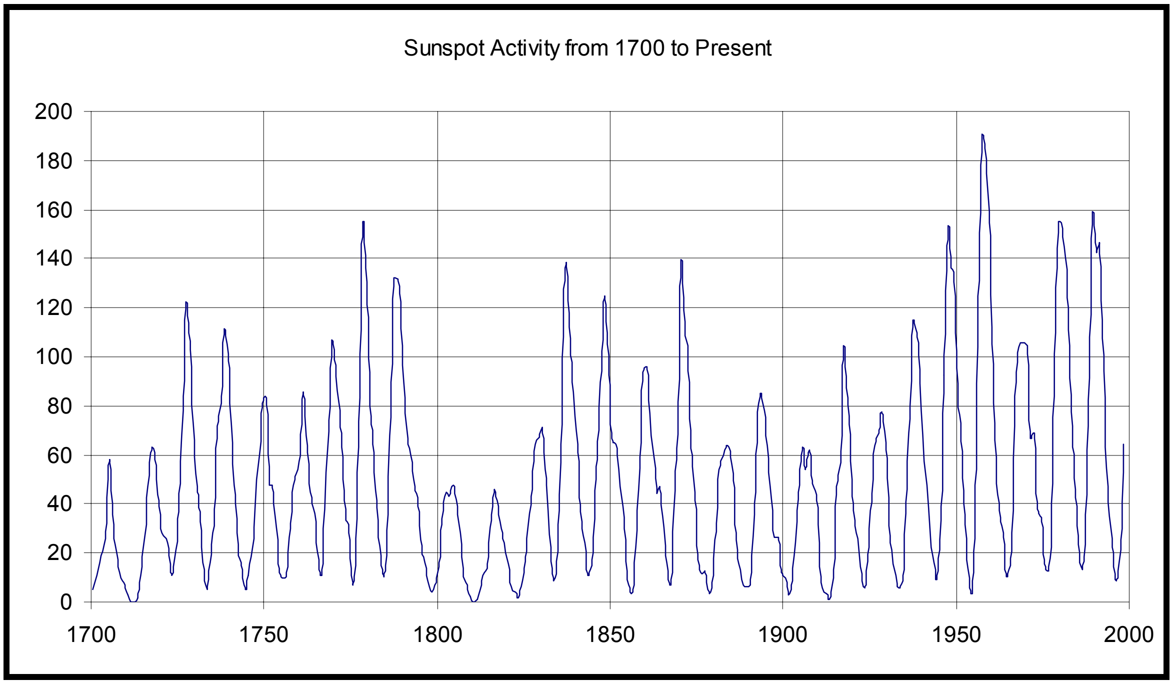

Figure 3, Sunspot Activity Dating back to the Late 1700s

Increased solar flare and sunspot activity causes ionospheric ionization that can affect propagation in the lower part of the VHF spectrum. When this occurs, frequencies between 30-50 MHz become capable of propagating signals for thousands of miles; accordingly, the potential for interference from far-away stations becomes much higher than during normal times. The impact on communications can be quite severe; for example, a station that, under normal conditions, communicates over a 50-mile distance could inadvertently have its communications totally disrupted by stations several states away. When interference is extreme, stations close to a base station site, or on portables only a few miles away, could meet similar fates and not be able to communicate. In other words, the radio waves "skip" over areas adjacent to the transmitter and interfere with other low-band systems in the county or state while at the same time not being able to communicate with a fellow user a few miles away.

Sporadic E-layer skip is another phenomenon caused by solar activity. This phenomenon is caused by changes in the ionization of the ionosphere's E layer, which is approximately 62 to 71 miles above the Earth's surface. When E-layer ionization conditions manifest, radio waves can travel anywhere from 100 to 1000 miles. The frequencies most affected by sporadic E are those between 28 and 50 MHz; on rare occasions, those effects can occur as high as 148 MHz[6]. The resulting problems caused by sporadic E-layer skip are similar to, but of shorter duration than, those experienced during sustained sunspot activity.

[6] Radio Waves and Communications Distance, Doug Demaw, QST Magazine, January 1985.

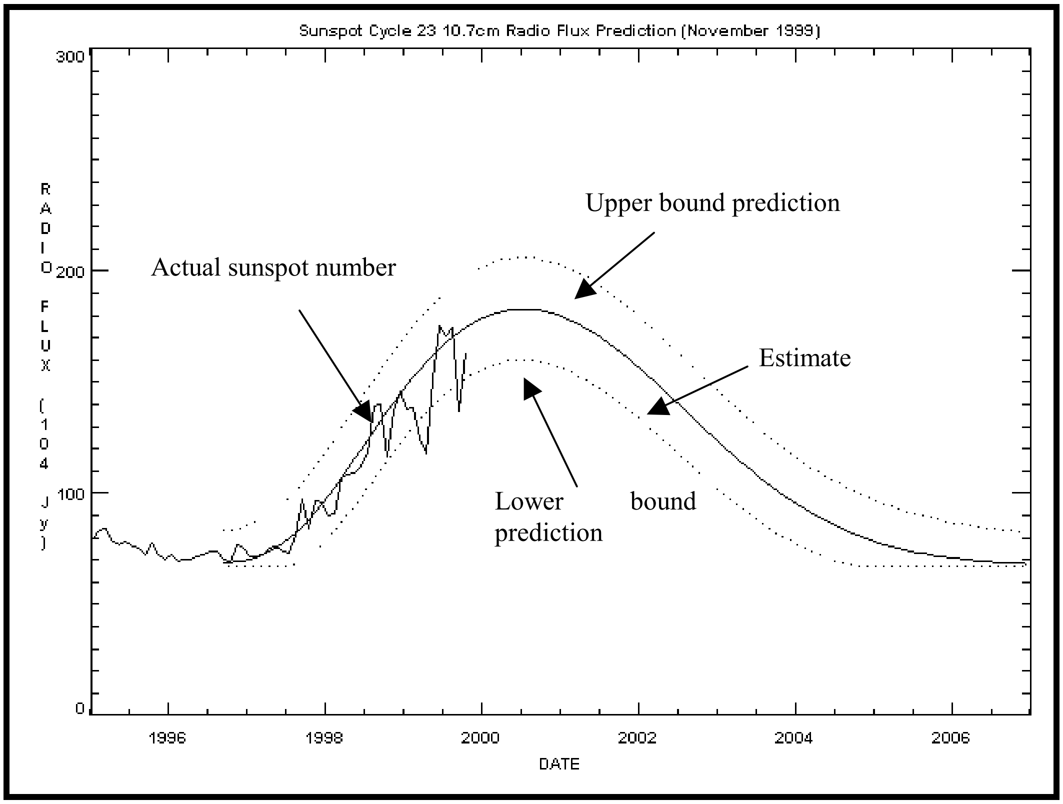

Figure 4, Sunspot Activity Predicted for Sunspot Cycle #23

The impact on Tompkins County communications is on paging. Because of the propagation being susceptible to ducting and isotropic scatter, poor in-building coverage, and susceptibility to solar activity, the County's radio paging system no longer adequately meets the needs of the in-building user community. Furthermore, low band's wide-area capability can be hit and miss; accordingly, with users being located all over the County, unreliable coverage could impact the strength of a response to a local fire call.

2.1.2 Advantages and Disadvantages to VHF, UHF, and 800/900-MHz LMR

VHF, UHF, and 800/900-MHz radio equipment offer different advantages, ranging from high-quality audio to good propagation. Radio operation at 800 and 900 MHz is less vulnerable to low-frequency interference sources such as lightning, motors, and impulse noise. UHF offers better noise performance than VHF. High-band VHF offers better natural and man-made noise immunity than low-band VHF.

From a coverage standpoint, the lower the frequency, the better the ground-wave propagation is. Low-band VHF has the best ground-wave propagation, followed by VHF, UHF, and 800/900 MHz, in that order. As frequency increases, the area covered by a single site decreases. The result of a decrease in coverage implies an increase in the number of fixed sites required to provide communications over a given region. The actual amount of decrease in coverage from increasing frequency depends greatly on factors such as the type of terrain and foliage and on whether in-building coverage is desired.

Figure 5 illustrates the multiplier expected for a migration from VHF to 800 MHz. Figure 5 is derived from empirical data taken from drive testing in Western New York State for the SWN project in 1998. This shows the best-case multiplier (unfoliated trees in an area that is overwhelmingly populated with deciduous trees). This figure would indicate that the multiplier for migrating from VHF to 800 MHz with a –100 dBm receiver threshold[7] would be about 3. In other words to get a –100 dBm coverage footprint in the 800 MHz band would require about 3 times as many sites as needed in VHF (for mobile service).

Figure 5, Measured 155/863-MHz Coverage Multiplier

2.1.3 Frequencies Used in Commercial Services and LMR

Commercial mobile data communications systems are most likely to be located in the 800- to 1900-MHz frequency bands. For North America, the spectrum used for wireless data communications is listed in Table 2.

Table 2, Mobile Data Frequencies

Service	Frequency Band
AMPS Cellular	824.01-848.97 MHz and 869.01-893.97 MHz
Narrowband PCS	901-902, 930-931, and 940-941 MHz
Broadband PCS	1850-1900 MHz
GSM 1800	1800 MHz
GSM 1900	1900 MHz
CDMA IS-95	800 and 900 MHz
TDMA IS-136	800, 900, 1800, and 1900 MHz bands
Enhanced Specialized Mobile Radio (ESMR)	900 MHz
Industrial Scientific and Medical (ISM)	902-928 MHz and 2.4-2.483 GHz
PCS	1850-1920 MHz, and Receive: 1930-1990 MHz

[7] This level (-100dBm) would be a good level for mobile receivers in a normally faded driving environment.

Commercial services also have siting requirements that are similar to (or greater than) those of public safety LMR. It is not expected that Commercial services would have any less siting needs than public-safety LMR. Actually, Commercial services in the "PCS" bands have even higher siting requirements than 800-MHz cellular services.

2.2 Conventional Radio Systems

Today's modern radio communications systems — with their many sophisticated features — can be looked at from two basic perspectives. The first and most fundamental aspect is that it is still a radio and still governed by the same engineering principles. Second, because of its complexity, the modern radio system can be viewed as a network. Radio communications can utilize one of three modes:

- When dealing with one-way, point-to-point, or broadcast communications, the mode is called *simplex*. In this mode, only one discrete frequency is needed.
- When the signals flow in two directions simultaneously (as in a cellular telephone), the mode of transmission is *full duplex*. Here, a pair of two discrete frequencies is required, one for transmit and one for receive.
- When the signal is relayed from one frequency to another, the communications is called a *half-duplex*, or repeater, operation. This mode of operation also requires a pair of two frequencies, one for transmit and one for receive.

The simplex mode, illustrated in Figure 6, is used by the most basic radio communications system. In a simplex mode of operation, information can only flow in one direction during a given transmission. The simplex mode is currently used for wide-area communications on the Tompkins County radio system. In the simplex systems that the County uses now, someone monitoring the radio does not hear the whole call (unless the monitor is close to the caller). Indeed those who are monitoring channels for situational awareness, unless they are within range of the person calling into dispatch, will get half of the conversation — that half being the transmissions of the dispatcher because dispatch is broadcasting from a high site on a hill or mountain. Repeater systems elevate this problem by "repeating" the subscriber's call portion from the high site.

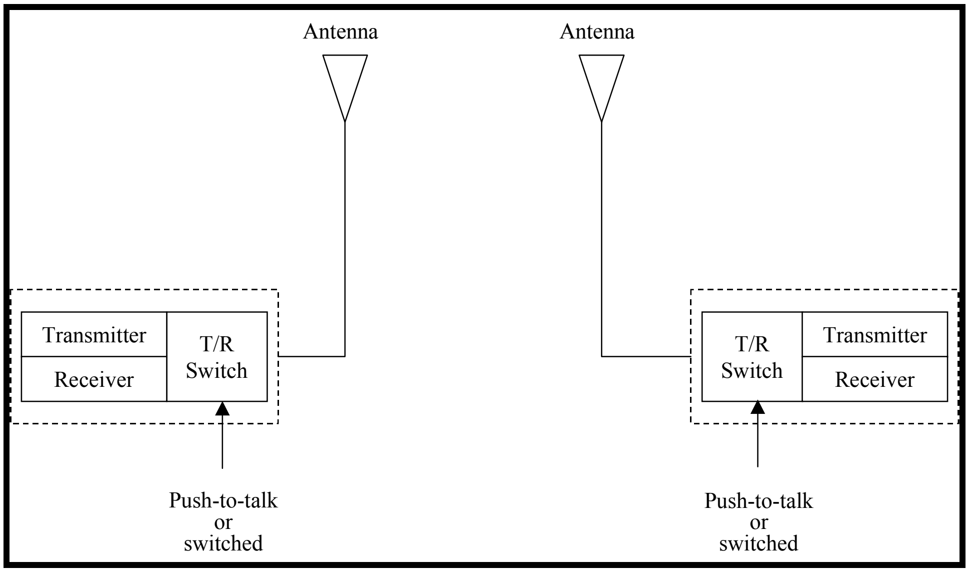

Figure 6, Simplex Radio Communications

Figure 7 shows a radio system operating in full-duplex mode. Notice that the stimulus to turn the radio on or off is missing, and that the T/R module is replaced with a combiner. The combiner is included to illustrate that a single antenna is used to transmit and receive simultaneously. Full-duplex operation is technically complex and is not presented in any detail in this report. Full duplex is the mode most cellular (and landline) communications systems use.

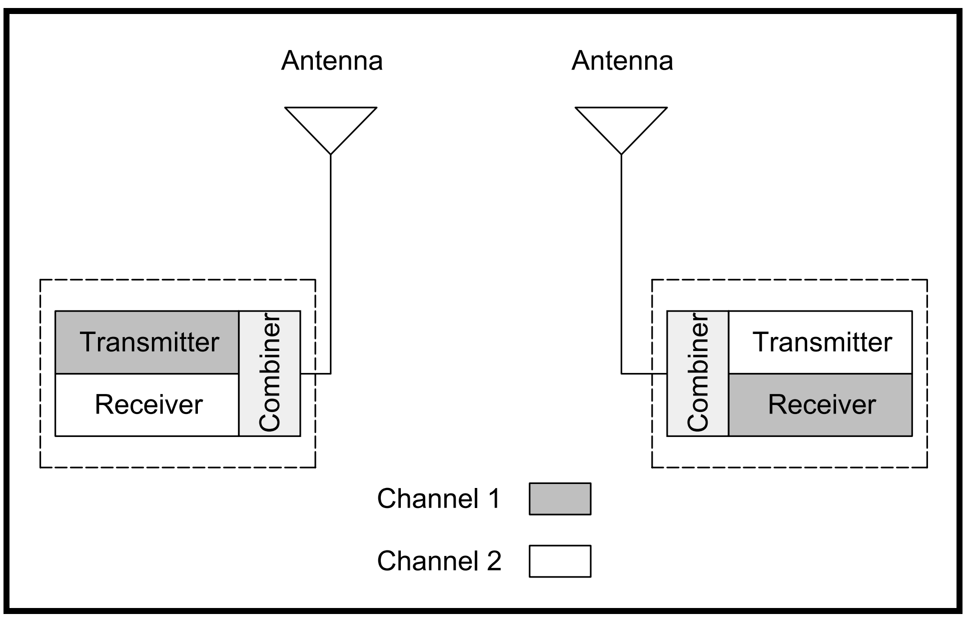

Figure 7, Full-Duplex Operation

Last, there is the half-duplex (or repeater-operation) mode of communications. This can actually be used to supplement or extend the transmission range of the other two modes of operation. With repeater, or "bent-pipe" operation, two frequencies are used. One component receives on one frequency, while another component simultaneously transmits at a different frequency. This is shown in Figure 8. The extra block at the right in the repeater diagram is the carrier-operated transmit (COT) unit. This device turns the transmitter on when the signal level exceeds a specific threshold. This keeps the repeater from being keyed-on all of the time. Half duplex is currently used as the local mode of operation by the DOT's communication system.

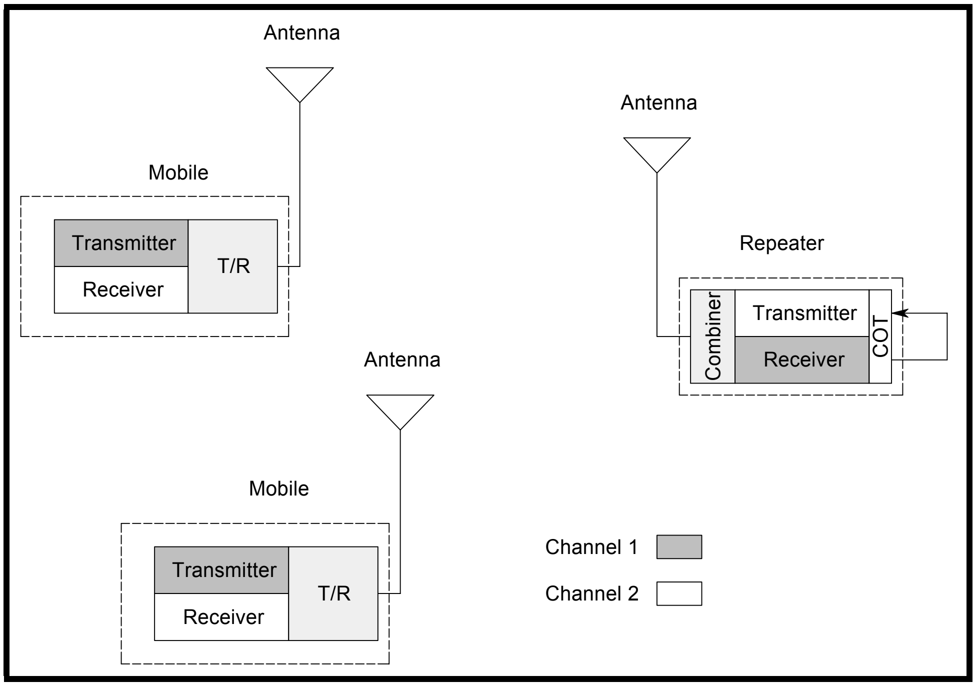

Figure 8, Half-Duplex, or Repeater-Operation, Mode

The three modes of operation (or combinations of them) that are simplistically illustrated in Figures 6, 7, and 8 are present in most land-mobile radio (LMR) systems. Even the most advanced trunked radio systems utilize these concepts, supplementing them with intelligent computer-controlled channel assignments.

Technology has taken these basic building blocks and, by combining digital signal processing and computer control, has developed the state-of-the-art trunked radio systems in use today.

Because of their lack of sophistication, older radio systems required little network-style management. The only computer interfacing that may have been required involved programming a radio's frequencies and, possibly, configuring tone-squelch settings. As more advanced communications systems were developed, network management became a significant requirement. This involved monitoring the status of multiple radios within a system, programming the radios over the air, monitoring and maintaining infrastructure components, and performing numerous other management functions. The added complexity has delivered increased capabilities not possible with older technologies.

2.3 Digital Voice, Data and Encryption

Currently Tompkins County only employs data on its 800-MHz subsystem or layer. Voice encryption is not used. For secured voice communications, scrambling is used in some limited applications. This section details and contrasts these applications with the digital domain.

2.3.1 Digital Voice Communications

Most conventional and trunked radio systems in use today are analog. This will change in the future due to spectrum regulations requiring all radios produced after 2005 to use 6.25-kHz channel spacing. Today's radio systems — whether trunked or conventional — utilize frequency division multiple access (FDMA) single channel per carrier (SCPC) for communications. Over the past few years, digital trunked radio systems have begun to become more popular. This is especially true for public-safety systems. One example of an all-digital statewide radio network is the Michigan State Police system.

To employ a digital modulation on a radio channel of known bandwidth requires the use of a signal processor called a vocoder[8]. The vocoder uses an algorithm that compresses human speech to enable it to fit in a small bandwidth allocation and still maintain good audio fidelity. Figure 9 illustrates how a vocoder works.

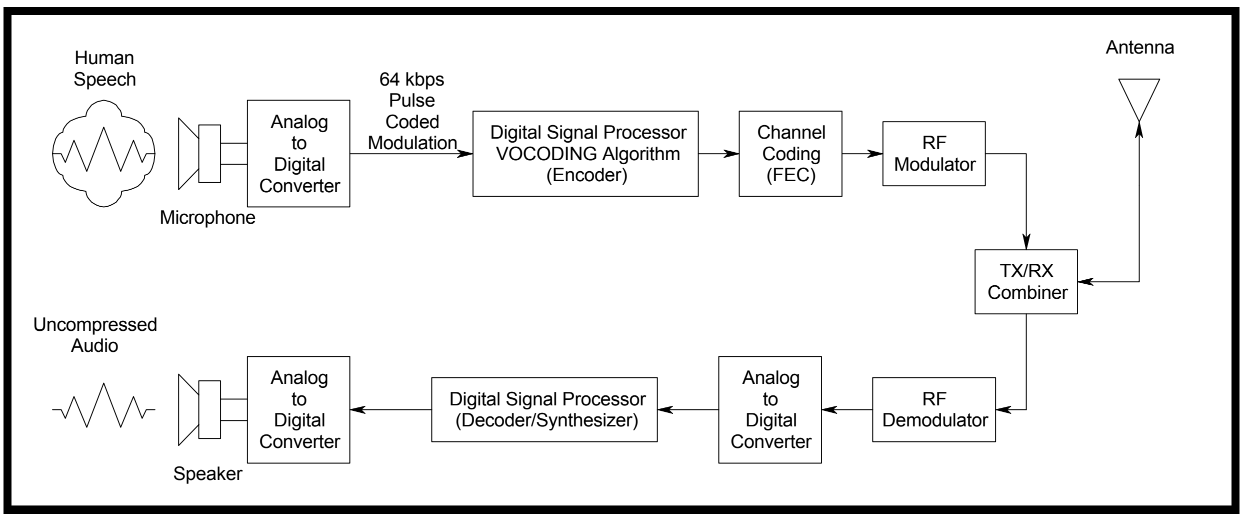

Figure 9, Operation of a Vocoder

Human speech is sampled at a high rate and is converted from an analog form to a digital data stream. The vocoder compresses the data, then error correction and channel coding are applied. Finally the data stream is modulated and transmitted over the communications channel. For the return path, a signal is demodulated, converted to a digital data stream, decoded, and synthesized to produce reconstructed audio at the speaker.

There are many voice-coding algorithms available. They have wide use, ranging from standard telephony to wireless communications. Table 3 lists the various vocoders in use today. The voice-coding methods listed are for low-bit-rate applications, such as wireless communications.

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[8] A contraction of voice and coder, vocoder.

Standard toll-quality uncompressed pulse-coded modulation (PCM) is 64 kbps. This is obtained by sampling analog voice at 8000 samples per second with an analog-to-digital converter (A/D). From Table 3 it is clearly seen that, as the compression gets smaller, the processing delay will increase. This should be taken into account when considering overall system delay. Voice encryption will also add more delay to both sides of a link. Voice quality at very-high-compression rates provides good communications grade performance. Vocoders running at 4 kbps or higher can provide near-toll to toll-quality speech reproduction.

Table 3, Vocoders for Low-Data-Rate Applications

Voice-Coding Algorithm	Bit Rate (bps)	Processing Delay (ms)
USFS 1015 Linear Predictive Coder, Tenth Order (LPC10e)	2400	135
Adaptive Multi-Band Excitation (AMBE)	4800	n/a
USFS 1016 Codebook Excited Linear Predictor (CELP)	4800	105
Codebook Excited Linear Predictor (CELP)	4800	105
Improved Multi-Band Excitation (IMBE)	7200	n/a
TIA IS-54 Vector Sum Excited Linear Predictor (VSELP)	8000	n/a
Codebook Sum Excited Linear Predictor (CSELP)	8000	68
DSP Software Engineering VoiceWave (DSPSE)	4800-12800	80-70
ITU G.728 Low-Delay Codebook Excited Linear Predictor (LD-CELP)	16000	2.5

The most popular vocoders in use for trunked radio applications are the APCO 25 standard IMBE and the AMBE. Other vocoder algorithms include G.729 and other lesser-known methods.

2.3.2 Data Communications

Two options exist in today's trunked radio communications systems. Data communications can be: 1) combined with voice or 2) operated in parallel with the voice traffic on its own dedicated channels. The jury is still out as to which option will provide the best performance. A few domestic manufacturers support voice and data coexisting on a trunked channel. These systems are all FDMA, which implies that, if a system is to support both data and voice simultaneously over a single channel, the traffic must be interleaved. If both were combined, the data being transferred would need to be dropped to a trickle to maintain good voice quality. To keep performance high, with the limited bandwidth available, the channel has to be shared. Therefore, when one form of communications is under way, the other must be scaled back. With a separate data system, both voice and data coexist on separate channels simultaneously. Therefore, a tradeoff exists between a combined and separate data capability. On one hand, the system can be self-contained; on the other hand, there are constraints on capacity. Likewise, with a separate data network, the customer has the potential for greater bandwidth and growth, but will incur added responsibility and costs of operation.

Data requirements will depend on the needs of the customer. Bandwidths necessary to meet traffic demands are dictated by many factors. Some users will only need to transfer short ASCII-text data files from a database. Others may need to transfer still or full-motion video. Some will require fingerprint identification. Table 4 shows the time required to send files of different sizes over a range of data rates.

There are many applications for wireless data in a modern public-safety communications system. Some examples include:

- Automatic vehicle location,
- Computer aided dispatch,
- Criminal database queries,
- Image transfers to and from the field, and
- Automated report processing.

Table 4, Transfer Times for Various File Sizes

	Data Rate (kbps)			
File size	**4.8**	**9.6**	**14.4**	**28.8**
(Kbytes)	*Transfer Time in Seconds*			
0.001	0.002	0.0008	0.0006	0.0003
0.01	0.02	0.008	0.006	0.003
0.1	0.17	0.08	0.056	0.028
1	1.67	0.83	0.56	0.28
10	16.7	8.3	5.6	2.8
100	166.7	83.3	55.6	27.8
200	333.3	166.7	111.1	55.6
500	833.3	416.7	277.8	138.9
1000	1666.7	833.3	555.6	277.8

2.3.3 Voice and Data Encryption

Digital audio has enabled more private communications. It is very difficult, but not impossible, to eavesdrop on a digitized audio transmission. Some digital protocols are open standards allowing individuals to monitor transmissions without breaking any legal sanctions. To have a secure trunked radio system requires the addition of data encryption. Many manufacturers provide data encryption as an option in their radio systems. One of the most popular data encryption methods in use is the Data Encryption Standard (DES), which was originally developed by IBM in the 1970s and was standardized by the United States Government in 1976. DES uses a 56-bit binary key with a total of 72 quadrillion possible combinations. Figure 10 shows the encryption/ decryption process operation.

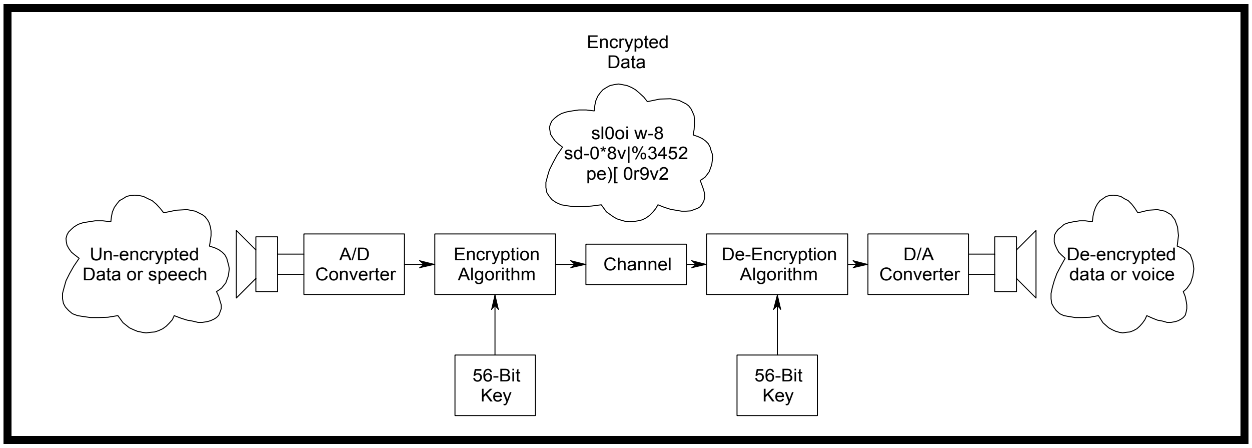


Figure 10, Encryption/De-Encryption Process

In Figure 10, the traffic could be either voice or data. When data is sent, the A/D and D/A converters do not apply. On each side of the process, a cipher key is required to encrypt and de-encrypt the data stream.

2.3.4 Voice Scrambling

Securing analog voice transmissions is accomplished by "scrambling." Other forms of securing analog voice transmissions include use of scrambling techniques. This can be applied to either conventional or trunked analog transmissions. The most popular form of scrambling uses frequency inversion synchronization (FIS). The three FIS methods include:

- Simple frequency inversion,
- Hopping inversion, and
- Rolling code inversion.

Hopping-inversion scrambling uses hop rates as high as 1 kHz to vary the inversion frequency. The hopping-inversion scramblers provide the highest level of security.[5] Other manufacturers have produced proprietary or time-domain speech encryption; these also produce a high degree of security.

There are, however, issues that should be considered regarding system performance when using voice scrambling. These devices do not add noise into a system, but do increase the level of noise that is present. At weak signal levels, the noise level present will be higher in the receiver. The scrambler will invert the noise, thereby causing an increase. Even though radio performance may have not degraded, the effect is perceived as a decrease of range. Steps can be taken to mitigate the effects of increased noise, but they can not eliminate it. Other factors that can effect performance include use in voting and simulcast systems[9]. With voting systems, the two primary problems can be loss of sync and poor audio quality. These problems occur if the system were to re-vote in the midst of a communication and from status tones used on some machines. In a simulcast system, care must be taken to minimize the effects of phase-received signals from multiple sites in areas where the signals overlap.

[9] These systems will be described later.

2.4 Voting Systems

A technique that is often used in conjunction with a simulcast network is called voting[10]. Voting is used to determine which repeater should be used in a given coverage area. The decision is based upon a comparison of the signal strength received at particular sites from a mobile. The site that receives the strongest signal will be the one that will be assigned to the roaming unit. The Thruway radio system uses voting methods for all of its divisions. Signals from mobile units can be received upon multiple towers simultaneously. Voting determines the tower receiving the strongest signal, then rebroadcasts this signal out over the entire division, using all towers.

The only serious disadvantage with a voting system is not having it work properly. If the system is too slow to determine from which site to select the audio, this could add response time to the dispatcher's call. If the system indicates false audio voting, the dispatcher may "steer" or select a radio site that is not near the caller and the dispatcher may not be heard.

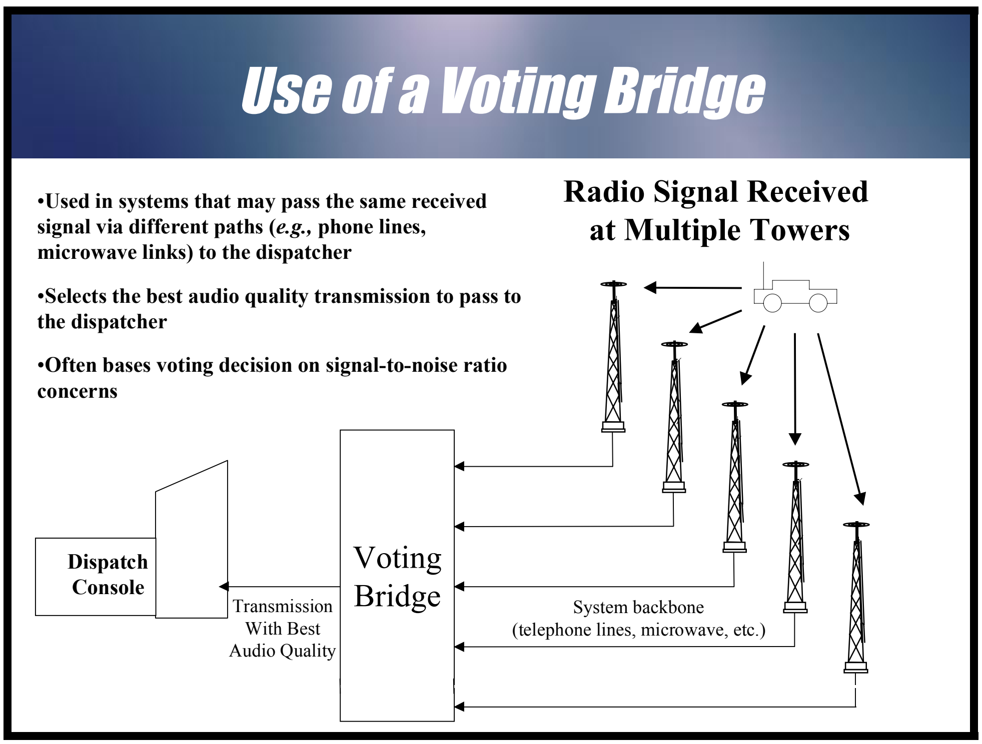


Figure 11, Voting Bridge (Comparator) Technology

2.5 Trunked Radio Systems

This section gives a basic introduction to what trunking is in both the wireline and wireless world.

[10] Simulcast systems will be described later. Voting does not have to be used with simulcast systems; indeed, many times it is used in multicast systems as the way to determine the best radio site to transmit from (best received site most often is the site nearest to the subscriber or user)

2.5.1 <u>Introduction to Trunked Radio Systems</u>

Today's modern trunked radio is an adaptation of a technique that was originally applied to the telephone industry. The basic idea behind trunking is based upon the premise that, if there is some number of customers who have a telephone, only a certain (smaller) number of them will actually use them at any given time. Therefore, if 100 people have telephones, the actual number of telephone lines needed may only be 10. If more than 10 people are trying to talk at once, the eleventh person will experience a busy signal. Figure 12 provides an example of a trunked telephone system.

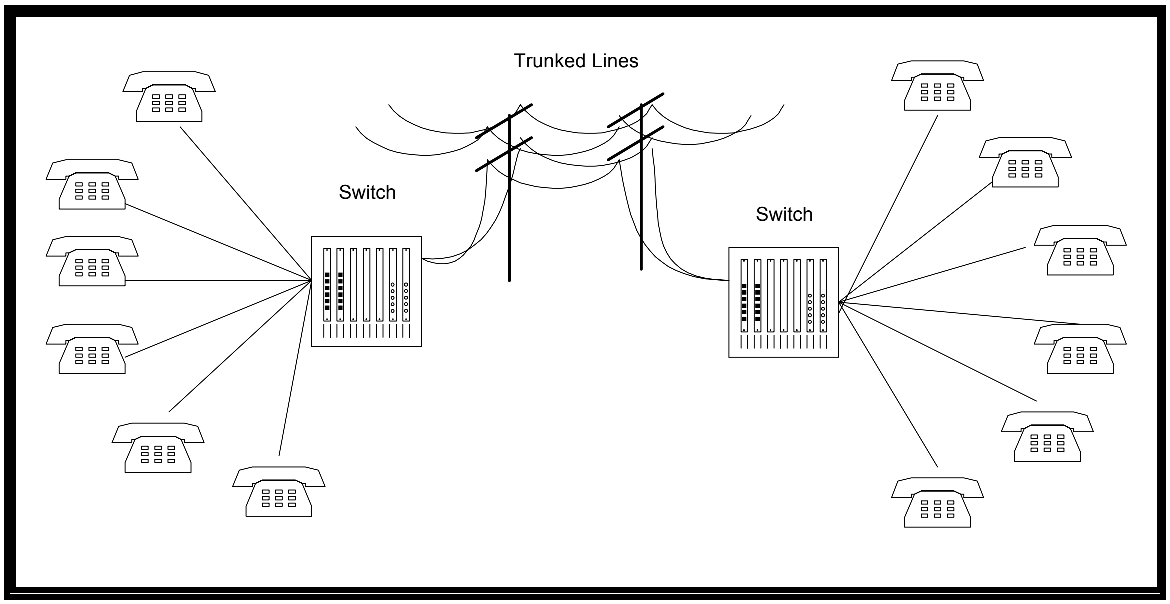


Figure 12, Telephone Trunked Lines

Every time a customer picks up the telephone and gets a dial tone, a trunked line has been assigned. When the caller connects with the party that he or she is trying to reach, the line will be tied up for the duration of the call. Both parties will be able to communicate on what has temporarily become their own private line. If there were no trunking of telephone circuits, an individual line would have to be run for every customer (which would be totally impractical), or there would be party lines. On a party line, a caller would pick-up the handset and could hear someone else on the line. As in a conventional radio system, the caller would have to wait until the conversation had been completed to use the communications channel. The theory behind telephone trunking also applies to modern day trunked radio applications.

The similarities between the early days of telephone with the early days of radio are not a surprise. Telephone began with the party line. Then came the trunked line and digital fiber-optic service. Likewise, in radio, there are only a finite number of channels available. The party-line equivalent of land-mobile radio is the conventional system. As the number of available frequencies decreases due to the increase in users, the push toward better spectrum utilization has driven development of innovative technologies like trunked mobile radio. Trunking offers a way to increase user capacity by intelligently managing a radio system's most valuable commodity — its spectrum.

2.5.2 Trunking vs. Conventional Operation

It is clear that trunking has many benefits over conventional radio communications systems. The main advantages are capacity, privacy, better utilization of frequency assets, and (as shall be seen later) features.

In a conventional system, one or two frequencies may be utilized depending whether the operating mode is simplex or through a repeater. Regardless of the channel type, only one conversation can exist at a time. Tompkins County has simplex (non-repeater transmission) on all its voice channels in both VHF and HF bands. This is a serious matter to those who would like to hear both sides of the conversation. In the simplex systems that the County now uses, someone monitoring does not hear the whole call (unless the monitor is close to the caller). Indeed those who are monitoring channels for situational awareness, unless they are within range of the person calling into dispatch, will hear only half of the conversation — that half being the words of the dispatcher, because the dispatcher is broadcasting from a high site on a hill or mountain.

Features like continuous-tone-coded sub-audible squelch (CTCSS) were included in systems to provide some level of interference reduction. CTCSS works by sending a sub-audible tone on a radio's carrier. When the radios waiting for a call detect the correct tone, their receivers will un-squelch. If all the members of a radio group have the same CTCSS codes programmed in their radios, they will be able to hear only the conversations of its members. Since no security has been added, eavesdroppers can pick up all conversations just as before. The only visible benefit to the radio operator is they don't hear other stations or interference until the radio un-squelches. CTCSS is used in the current Tompkins County system to avoid voice-traffic interference between neighboring tower coverage zones.

Another feature available to conventional system is telephone interconnect. Through the use of a telephone interface, it is possible to have half-duplex telephone conversations. Due to the party-line attributes of the system, privacy is non-existent.

Trunked radio systems are quite an advancement over their conventional non-trunked counterparts. From the hardware and system management end, there are many differences. Figure 13 shows a generic trunked radio system. Some of the hardware that is required in most trunked systems includes:

- Trunked system site controller(s),
- Control channel(s), and
- Working channels.

Unlike conventional radio systems, trunked systems must utilize a means of determining channel access for all mobiles and portables. This is commonly handled by what is known as a control channel. There are a number of different control-channel access methods in use today, the two most popular being distributed and dedicated. Regardless of the method used, the control channel sends out data to the mobiles on the system in a data stream. The information contained in this transmission tells the mobiles the status of the entire system. When a call has been initiated, the packet will be sent via the control-channel method to set up the working-channel assignment. If there is an open channel, the connection will be made, and the contacted party's radio will un-squelch. If there is no channel available, the caller will be blocked. At this point, the caller will need to wait until a channel has been freed up for use.

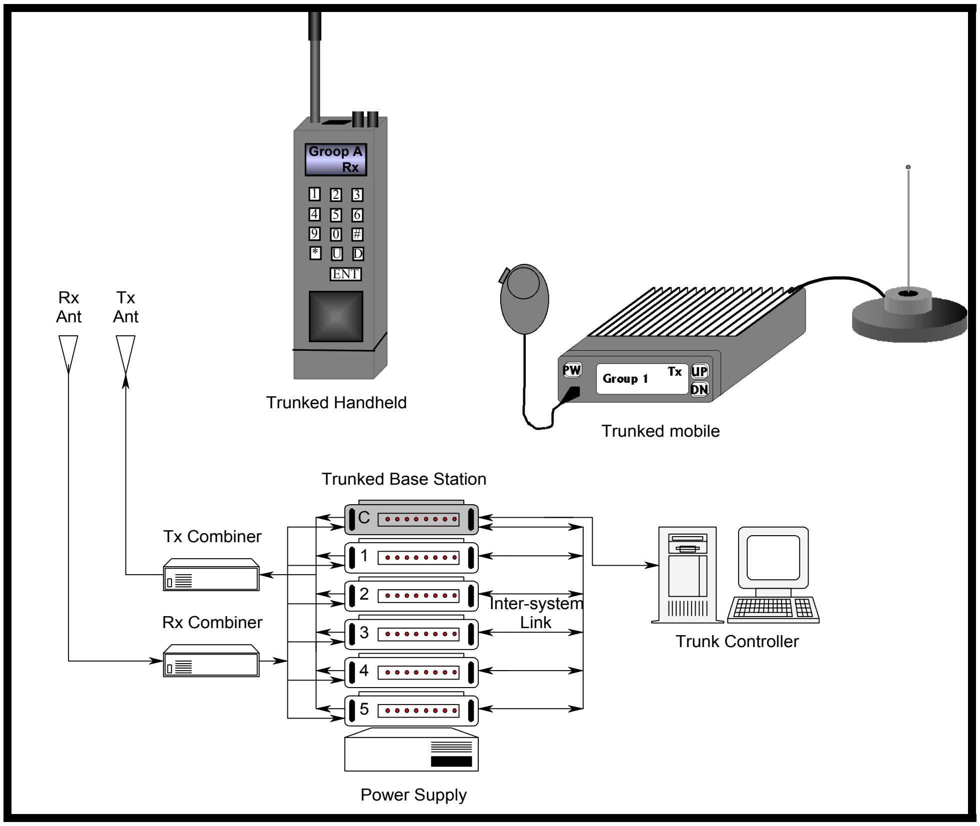


Figure 13, Generic Trunked Radio System

Unlike a conventional system using CTCSS, the calling party in a trunked radio network can make the call heard by any number of users. For example, if it is necessary to alert a large number of units that something is wrong, the call can be made to all units within a group or on the system. If only one party is to be contacted, only the caller and the unit being called can be privy to the conversation.

What gives the trunked radio user more privacy than the conventional user is how the channel assignments are made. Conversations between units may not always occur at the same frequencies. For example, if a channel is occupied and has been designated to a particular user or user group, other system users and user groups will be given the next channel available. This makes trunked transmissions more difficult to intercept.

Communications are also not relegated to analog voice. Transmission of voice can be done digitally. A voice coding algorithm (vocoder) samples the human speech (which is analog) and converts it to a digital stream that is packetized and sent over the radio link. To increase the level of security, encryption can be added. This makes it virtually impossible for eavesdroppers to decipher the communication.

The diagram of Figure 14 represents a six-channel (including the control channel) trunked radio site. Each channel represents a frequency pair — one transmits and the other receives. In this example, the channel labeled "C" is designated as the control channel. The other repeaters in the diagram (identified as 1 through 5) are the working channels that are used for voice communications. Most trunking systems can range from 2 to more than 20 (and in some cases up to 32) channels. Depending upon the type of trunking system, the number of sites that can be supported will range from one to thousands.

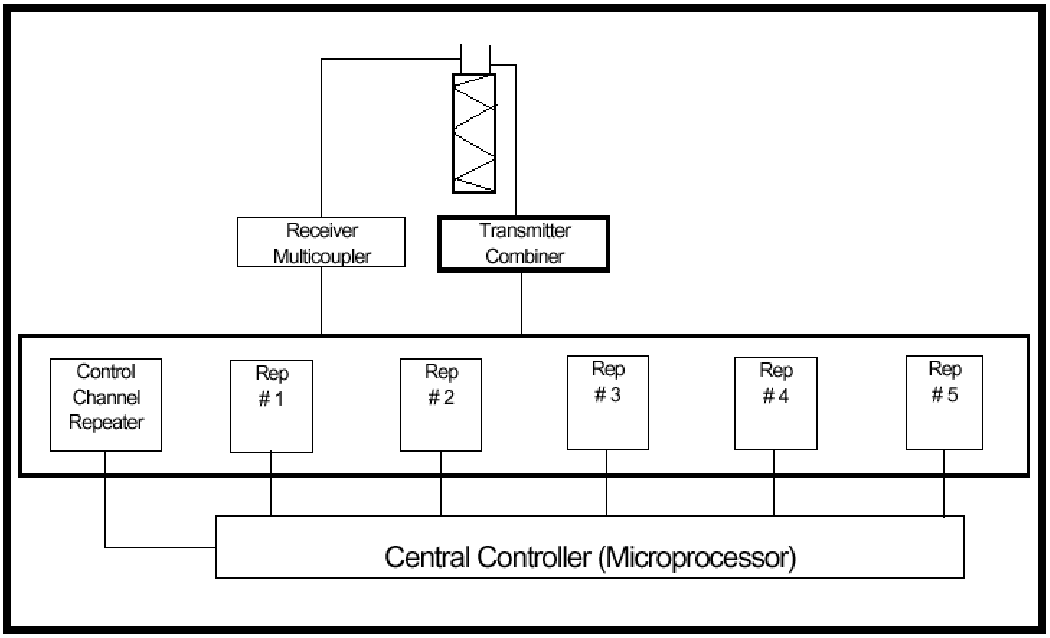


Figure 14, Example Five-Channel Trunked System with Control Channel

2.5.3 Trunked Radio Technology

Having compared the differences between conventional and trunked systems in the previous section, this section concentrates more on the significant aspects that allow trunked technology to operate.

2.5.3.1 Control-Channel-Access Method

There are fundamental elements that are common to most trunked radio systems. The trunked system configuration has a control channel to manage channel assignments. The method by which the channels are allocated is called the control-channel-access method. In the United States, there are predominately two access methods in use:

- The dedicated-access method and
- The distributed-access method.

Dedicated-Access Method

The dedicated-access method requires that one of the channels in a trunked system be used full time as the control channel. One unit handles all channel assignments and features of the system. If a system is comprised of 20 channels, at least one of them must be used as a control channel. This cuts the available serving capacity down from N to N-C, where N is the sum of the number of working and control channels, and C is the number of control channels. The system must also be able to compensate for control-channel failure. This can be done by the use of an intelligent site controller.[11] The site controller is another device that can be considered to be mission critical. Figure 15 shows the hierarchical layout of a trunked system. The site controller manages the entire site, and the control channel runs the trunked operation.

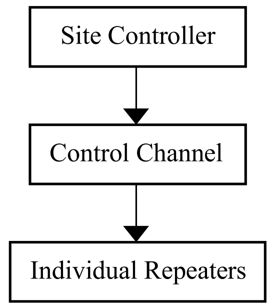


Figure 15, Trunked Radio System Hierarchy

If site controller should fail with no redundancy, the entire operation could be brought to a halt. This, however, can be compensated for. Some manufacturers have built into their systems a feature known as *fault tolerance*. The feature is incorporated at various system levels. At the control-channel level, it is known as falling under Association of Public Safety Communications Officials (APCO) APCO-16B compliance. Fault tolerance has been implemented using various methods. Com-Net Ericsson, for example, has incorporated within its Enhanced Digital Access Communications System (EDACS) a feature enabling any channel to assume control-channel functions if a failure should occur. This allows the system to continue trunked operation at a basic level. Figure 16 shows a fault-tolerant hierarchical diagram, and illustrates how a system could continue despite the failure of either the site controller or a control channel.

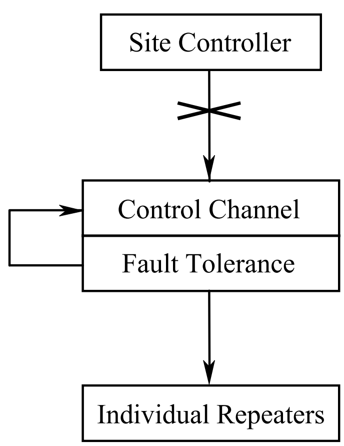


Figure 16, Fault-Tolerant System Hierarchy

[11] The site controller is a processor or on-site computer that handles the control of the on-site repeaters. The site controller is linked (via the transport medium, microwave, fiber, or T1) to the mobile telephone switching office or MTSO. The MTSO is the switch that handles communications among the radio sites.

Distributed Access Method

A second control-channel-access method is called distributed control. In such a system, each working channel in the site handles control-channel functions. Each channel in the system transmits data that contains information concerning which repeaters are free or are busy. Individual mobiles deal with channel congestion. The bulk of the system management is, therefore, shared with the mobiles. Distributed-access systems may also offer more system capacity, since no single individual channel needs to be dedicated as the full-time control channel.

The typical time to set up a channel assignment varies from system to system. Time figures can range from 200 milliseconds (ms) to 750 ms. Most popular trunked radio-control access methods will set up a channel in 250 ms. Sources of delay are introduced by auxiliary hardware — such as multiplexers, voting bridges, etc. — that is used in networking sites together.

Dedicated-Access Method or Distributed Access Method

Of these access methods, no particular approach is superior. Manufacturers have their method integrated into the overall system offering. Generally, among proprietary and standard trunked systems, Dedicated Access Method is more popular.

2.5.3.2 Fleet Organization

In trunked radio systems, there can exist an arrangement by which the individual users are organized in a system. Each radio that operates in a system is given a unique identification number. These are known as addressable units supported by the system. The number of addressable radios within a system can range anywhere from tens of thousands to millions. A trunked site with some number of channels can support a portion of the maximum number of users; the total number of radios a site can support will vary depending upon the manufacturer (another factor is how many channels are at the site). On a given system, there can be a number of subgroups called talk groups. The number of these talk groups can range from hundreds to thousands. With a capable network design, a system can be extended to large number of both talk groups and addressable radios.

2.5.3.3 Types of Calls

With the organization of the radio-addressing structure, it is logical to influence the way calls can be made over a trunked radio system. In a conventional radio system, a dispatcher could make only two types of calls. One would be the dispatch type to all units. The other would be to a specific group (by CTCSS tone encoding so as not to un-squelch the radios of other groups). In a trunked system, the options are much more sophisticated. The types of calls that can be made include mobile-to-mobile, emergency, group, and dispatch calling.

Mobile-to-mobile calling can be made through the system and, in most cases, even off the system using conventional radio-to-radio mode. Calls made using the system require the caller to know the ID of the unit that is to be called. Units outside of a particular talk group on the same system can contact one another when necessary.

Emergency calling is self-explanatory. Depending upon the trunked radio system, this can be a single button that, when pressed, initiates a call. The control channel will then raise the priority level of the unit in trouble, or move it up to being next in line if all repeaters are busy.

Group calling is another useful feature of trunked radio systems. The dispatcher (and individual users) can make calls to all units in a group at once. Like group calling, system-wide calling can be performed as well. This permits the notification of all mobiles in a system.

Other types of calls that can be made in a trunked system involve telephone interconnect. This capability exists in most systems. The mobile user has the ability to place telephone calls in a fashion similar to landline telephony. The user usually gets a dial tone indicating connection to the public switched telephone network (PSTN). They still usually function in Push-To-Talk (PTT) mode, but users connected to the wireless subscriber via the PSTN can talk and listen simultaneously (duplex calling) at their end. The feature is handy for contacting a party who may be completely off the radio system — at home, in the office, or only with a cell phone. When placing such calls, the trunked radio system should have dual-tone multi-frequency (DTMF) capability for dialing purposes. To enjoy the same performance that cellular telephone operation affords requires that a radio be capable of full-duplex operation. With half-duplex operation, calls can be made; however, the operator and the party being called must realize they are using a two-way radio. Although two channels are being used, only one person can talk at a time. Telephone interconnect is a feature that should be used sparingly, as the long conversation times (typically much longer that standard PTT transmissions) can easily overload a system if misused.

2.6 Simulcast

To extend the coverage of a trunked radio system into areas that do not have heavy traffic loading, a method called simulcast is often used. Simulcasting transmits, from different locations, signals that contain identical content. Figure 17 shows an example of a simulcast system. The individual sites are linked together through wireline, fiber, or point-to-point microwave links.

Simulcast can boost the coverage probability over an area without the need to practice frequency reuse (i.e., use different frequency sets in different areas). This section provides an overview of the considered aspects for the non-specialist with a basic understanding of the science of wireless communications. For the interested reader who may be seeking further clarification of these simulcast aspects and terms, Gray[12] offers an excellent primer on this topic.

Simulcast operation occurs when the same modulation is transmitted simultaneously from more than one site having the same carrier frequency. All communications applications must deal with the needs of the users by addressing the fundamental aspects of coverage and capacity. Simulcast operation is one way of addressing the coverage and capacity demands on the network.

Simulcasting can increase the probability of coverage with less spectrum than would be demanded by a multi-site frequency reuse plan. Capacity demands can be served well in some applications by simulcast, because the users of a trunked group can not be served by one site alone. Simulcast can keep these wireless users together because the group can be raised network wide by one duplex frequency, thus eliminating the need to coordinate roaming amongst the users in a mobile environment.

[12] Gray, David Gary, "The Simulcasting Technique: An Approach to Total-Area Radio Coverage," *IEEE Transactions on Vehicular Technology*, Vol. VT-28, No. 2, May 1979.

Public-safety and law-enforcement applications of simulcast offer the attraction of increasing coverage among groups that are highly mobile and have a need to communicate to each other (dispatch). To these groups, simulcast offers a great deal of spectral efficiency as well as increased coverage probability. The mobile user needs sufficient signal from any one of a number of sources to be covered. Therefore, the coverage probability is higher in areas where there are two overlapping sites than would exist with only one site.

Simulcast requires, however, very stable transmit frequencies, as well as precisely matched audio delays, to avoid degraded audio quality. A reality of the simulcast application is that, even when great care is taken to adjust the system, the physical distances, topological, and seasonal realities of any configuration result in some distortion in all but the simplest of simulcast networks. Whenever possible, simulcast design should place non-capture areas over locations that have less importance (such as forests or lakes) or areas where patrols are highly mobile and the use of portables by officers on foot is low.

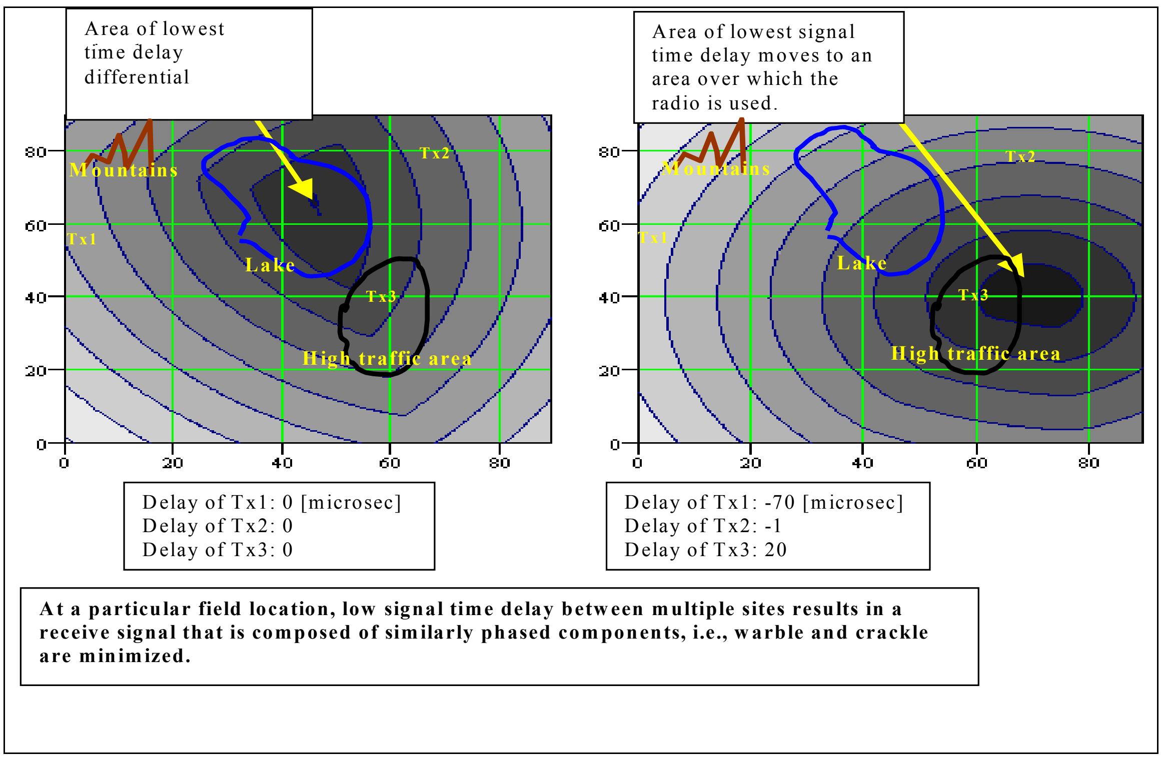


Figure 17, Simulcast Coverage Example by Time Domain

Figure 17 displays a sample map of a typical three-site simulcast system, overlaid onto a time-delay graph. The two systems in the left and the right are identical, with the exception of the launch delays. The system on the left represents no launch delays, while the one on the right depict delays of –70, 1, and 20 μsec for transmitters 1, 2, and 3, respectively. The map depicts two areas where coherent phasing is not usually an issue, i.e., over the lake and mountainous rocky area and also depicts a high-traffic area, in which coverage is a design requirement. The darkest areas of the graph (corresponding to low received-signal time differential and thus similarly phased receive components) may contain non-capture areas.

Non-capture means that a tuned FM receiver in that area will switch from one transmitter to another, just as an FM receiver will flutter between a desired signal and Gaussian noise. However, even if non capture in these dark areas occurs, due to low received power differences, the composite received signal will be free of pops, clicks, and excess noise due to mismatched phases. Note that from the system on the left (no launch delays) to the system on the right (proper launch delays) the dark area changes shape and is moved away from the less useful areas of the map to more useful and heavier traffic areas.

2.6.1 Two-Signal Simulcast Analysis

This section provides a snapshot of issues in simulcast modeling. This discussion is a very brief overview of the theory of simulcast operations and is meant to help the reader understand the rationale for selection of the aspects of simulcast operation detailed in the following section. Also this section can aid the decision-maker in deciding how to detail an acceptance test procedure (ATP) for a simulcast system.

The method for analysis of simulcast systems with more than two sites is a reduction to a two-site model. This discussion begins by introducing the two-site analysis.

First consider, as Hess[13] does, two received FM signals that can differ in modulation index, carrier frequency, time of arrival, and the audio phase. The time amplitude of the signals is

$$e_1(t) = E_1(t)\sin[\omega_c t + \beta_1 \sin(\omega_m t)]$$

Equation 1

$$e_2(t) = E_2(t)\sin\{(\omega_c + \delta\omega_c)(t - t_2) + \beta_2 \sin[\omega_m (t - \tau - t_{2)})] + \phi\}$$

Equation 2

β represents modulation index, $\delta\varpi_c$ is the carrier frequency difference, t_2 is propagation delay difference, τ is the audio phase delay, and ϕ is the carrier phase difference, where signal 1 ($e_1(t)$) is the reference.

An ideal limiter or discriminator, subjected to a composite of more than one signal, will create a voltage that is directly proportional to the rate of phase change over time, or:

$$V(t) = \frac{d}{dt}[\angle r(t)] .$$

Equation 3

Further:

$$V(t) = \beta_1 \omega_m \cos(\omega_m t) - \frac{d}{dt}\left[\tan^{-1}\left(\frac{x(t)\sin(\theta(t)}{1 + x(t)\cos(\theta(t)}\right)\right].$$

Equation 4

[13] Hess, Gary C., *Land-Mobile Radio Systems Engineering*, Boston, Artech House, 1993.

The first term equals the desired signal. The second term is the distortion that is experienced by the user radio. If the signals are nearly constant over the time in use, then *x(t)* is equal, has a continuous x value, and the distortion component equals $\left[\theta x(x+\cos\theta)\right]/(1+2x\cos\theta+x^2)$. When a signal arrives at the user equipment out of phase $(\theta = \pi)$, the distortion term becomes $(\theta x)/(x-1)$. Thus, values for x will drive this to positive infinity for x values decreasing towards unity and toward negative infinity for x values increasing towards unity.

Realistically, the limiter will not be perfect and the narrow bandwidth of the discriminator will set a limit on the amount of distortion, poor amplitude and phase match, and can clearly lead to conditions where the distortion is intolerable.

2.6.2 Basic Aspects of Simulcasting

Having reviewed the considerations that go into simulcast system design, this discussion can better detail the basic considerations in specifying a simulcast system[14]:

- Carrier frequency offsets between any transmitters in the system should be minimized. Any unintentional asynchronous carrier signals can result in audio distortion in user equipment.
- Multipath fading is unchanged by such a system; however; the effects can be greatly reduced in a synchronous system.
- Fading can seem to 'move' about because of carrier drift. This can be observed when a vehicle is not moving and the fading returns to the same position over time. A common complaint of a simulcast system with frequency drift is that the 'dead spots' or areas of bad coverage seem to occur in a location that previously had good coverage.
- Obstruction losses due to topology (e.g., hills) and the ground cover (e.g., trees and buildings) can be greatly reduced by a simulcast system. This is due to the multiple transmitter arrangement.
- System reliability and the audio quality of user equipment increase as the distance between multiple transmitters decreases. Conversely, system reliability and user-equipment audio quality decrease as the distance between multiple transmitters increases.
- Unequal effective radiated powers (ERPs) between sites contribute to poor system reliability and user-equipment audio quality (distortion).
- The greatest cause of poor audio quality or distortion in a simulcast system is audio and phase-level differences between the site transmitters.

[14] This section considers the engineering areas unique to simulcasting. Such issues as maintenance and life-cycle costs are important, but not unique to simulcasting, and are not considered here

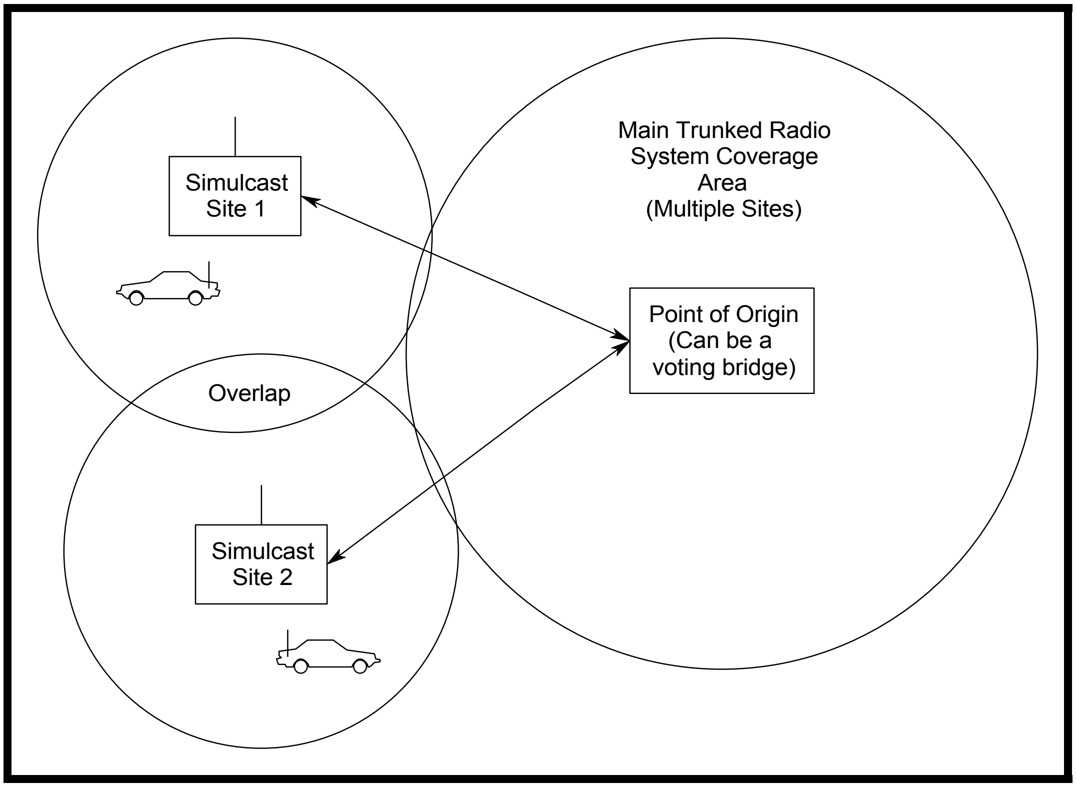


Figure 18, Simulcast Example

In some cases, a small area of overlap will occur, which can yield interference problems. Special care must be taken to minimize its effects, especially when using a digital modulation or in conjunction with scrambling. Simulcasting is also useful in situations where there are not enough frequencies available in a crowded environment. In such a system, a common set of frequencies is shared over a large area to make the most efficient use of limited spectral resources. Multicasting, which is similar to simulcasting, uses different frequencies to cover a wide area. With multicasting, the overlap problem can be alleviated in the areas where overlap would occur if common frequencies were used.

2.7 Microwave Technology

Microwave radio usually refers to two-way point-to-point fixed links. Microwave radio links cover the spectrum from 300 MHz to 60 GHz. Microwave systems are usually preferred to leased lines[15] for a number of reasons:

- Microwaves do not require right-of-way servitudes.
- Microwave systems are more cost effective at lower capacities.
- Cable Systems have a linear cost profile: the longer the cable, the high the cost.

[15] Leased lines can take the form of a number of media — like fiber or copper or T1 lines. "Leased lines," as used here, refers to transport connectivity that is provided by a commercial third party.

- Radio Systems have a stepped cost profile proportional to the number of radio repeaters required, making them less costly for longer routes.
- Microwaves never have the problem of altering the terrain or digging up roads to place cables for ultra long distances. Stringing cable is not only costly, but also has significant delays associated with it.
- Microwave systems can provide high-capacity connectivity.

Since microwave links operate over the same area all of the time (i.e., they are fixed links), it is very important to classify the terrain over which the signal propagates and the ambient weather conditions. The terrain is analyzed by using topographical maps or Geographic Information System (GIS) digital terrain models or digital elevation models (DEMs). The information drawn out of these maps is a cross section of the terrain between directly linked microwave sites. These cross sections are known as path profiles.

2.7.1 Microwave Frequency Bands

The microwave frequency bands used are in the 960-MHz and 2-, 4-, 6-, 11-, 18-, and 23-GHz areas. Microwave systems may be analog or digital. Microwave propagation is “line of sight” (LOS). Microwave transmission links in the northeast (like in Tompkins County) generally do not exceed 25-mile increments in bands up to 12 GHz; for longer shots they are repeated. At 10 GHz, rain attenuation usually causes a distance limitation, so repeaters must be applied.

2.7.2 Protection of Microwave Communication Systems

Microwave terminals are available in non-protected and protected configurations. A protected microwave system provides full duplication of all active elements (RF transceiver and baseband components). Some protection schemes available are frequency diversity space diversity, and monitored hot-standby. Space diversity and frequency diversity provide protection against path fading due to multipath propagation and provides against equipment failure.

Important microwave communication design steps are:

- Preliminary Network Design,
- Frequency-Management Considerations,
- Site Selection and Planning, and
- Line-of-Sight Establishment.

2.7.3 Network-Management Systems

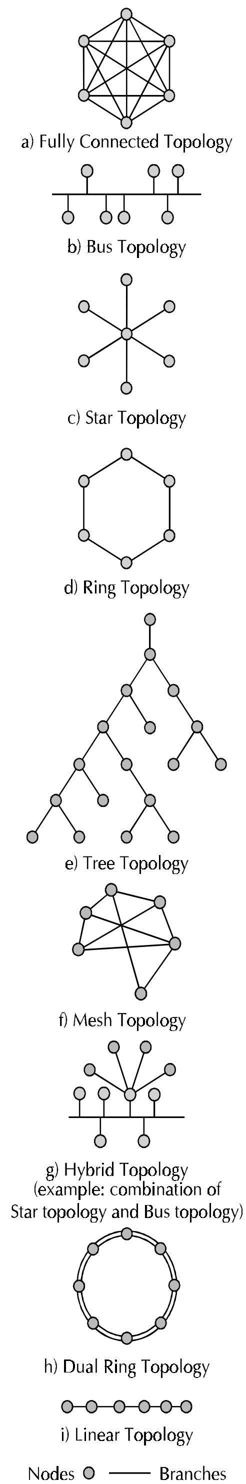
Network-management systems are essential in a transmission network. They consist of a centralized automatic control system that uses computer technology to provide information to operating and maintenance personnel.

2.7.4 Network Designs

The topology of the structure can be modeled by symbols that are standard throughout the network.

There are two types of microwave network topology in use:

- Star Networks
- Ring(loop) Networks



Star Networks

The main building blocks are multiple hub sites positioned in strategic locations.

Ring or Loop Network

Loops of links that provide for diverse routing in a network infrastructure. This allows a redundant route to be available in case the main route fails.

Preliminary Network Diagram

The preliminary network diagram can help to locate spots of vulnerability within the network. The preliminary network diagram can then be used to forecast and to determine the evolution of the system and the growth that may need to take place. The change in capacity that will take place is looked at with respect to the number of links that need to be added. The preliminary network diagram tells us the different lengths of the links and the capacities of the links that are required.

Path Engineering: General Clearance-Path Rules:

- On any path that propagates frequencies of 7 GHz and over, allow a clearance of 0.577 F_1 over any obstruction at k=0.7.
- On any path < 1GHz, allow a clearance of 1.0 F_1 over obstructions at k = 4/3.
- For any path at any frequency up to 6GHz, allow a clearance of $0.3F_1$ over obstruction at k=2/3.
- For knife-edge diffraction paths, allow a grazing clearance over obstructions at k= 2/3.
- The most critical consideration is that the link is line of sight (LOS).

Sometimes engineers will prefer to use a near-field clearance criterion. This is designed to minimize backscatter. It can consist of a cylindrical volume clear of obstructions with a radius of about 100 meters and that extends 1-2 km in length from the antenna.

2.7.5 System-Gain Calculations

A practical measure of transmission performance capability is system gain. It takes into account key radio design parameters (except distortion). System gain is defined as the difference between transmitter output power and the thermal noise receiver threshold, which is specified at a specific bit-error rate. For proper operation, its value must be equal to the sum of all the total gains and losses in the radio signal path. A large system gain will ensure robustness to performance degradations. It is defined as:

$$G_s = P_t - S_{\min} \geq L_s + L_f + L_b - G_T - G_R + F_M$$

where: P_t ≡ transmitter power output at antenna circulator port [dBm],
S_{min} ≡ undistorted received signal level [dBm] for a specified BER,
L_S ≡ free space path loss [dB],
L_f ≡ total feeder loss [dB],
L_b = atmospheric loss,

G_T, G_R ≡ boresight transmit and receive antenna gains [dB] at f [MHz], and
F_M ≡ fade margin determined by thermal noise.

2.7.6 Site Selection and Planning

Minimization of sites will help to control real-estate investments or site-leasing costs. In addition, the cost of construction is lower, and the overall planning process is made simpler. Regardless of the number of sites (few or many), no single network element should be considered in isolation. The propagation regime is a holistic one, and, therefore, encompasses all of the sites concurrently.

In every generalization, there are exceptions, but some overall characteristics of good microwave sites are:

- high elevation,
- sharing of towers, poles, wireless and cellular equipment, and indoor shelters
- accurate loading calculation of antennas on the towers that take into account ice and wind loading,
- adequate service access is considered, and
- future growth is always considered.

2.7.7 Establishment of Line of Sight

Electromagnetic waves disperse (spread out) as they move out from their source. Because of this spreading out, the signal may not completely clear possible obstructions. (Fresnel Zone clearance).

There are two basic ways of establishing line of sight:

- creating the path profile and/or
- surveying the actual path.

The path profile is established from topographical contour maps, which can then be translated into an elevation profile of the land between the sites. One disadvantage to this method is that obtaining maps that are accurate enough (to translate into a profile) is a difficult task.

A survey of the path can be done by visiting sites individually to observe that the path is free of obstructions. When this is done it is important to consider future obstructions to the path, such as foliage and tree growth, future building plans, nearby airports, or any other transient traffic considerations.

Routes of line of sight are dependent upon factors such as link length and site locations.

2.7.8 Process Order

When the specifications are complete, the work order can be initiated. The work order should contain all the information necessary to construct the cellular site, including civil cellular and microwave data.

Information relevant to the work order can be:

- final Routing diagram,
- path calculations,
- tower profile to indicate antenna heights,
- rack profiles,
- floor plans,
- radio installation information,
- power consumption, and
- growth considerations.

2.7.9 Frequency Management

The next step is to determine if these requirements are achievable with the current frequency-management availability. The most efficient use of the frequency spectrum can be made by using the lower frequency bands for longer paths and higher frequency bands for shorter paths. The FCC's rules regulate the link length. This part of the design process will also take into account — on a path level and a network level — the availability of the system that is required for the users.

Path availability of a specific microwave link is influenced by a number of factors:

- Net output power (EIRP),
- Free space attenuation, and
- Receiver sensitivity.

Local frequency management will also regulate the EIRP, which impacts frequency reuse and management. Planning networks with unusually high EIRPs can limit future frequency reuse. Determining if the local frequency-management authorities will support your objectives is an important consideration.

Economical and engineering benefits will be gained by sharing civil infrastructure, such as towers and equipment housings. The total number of sites to be built (and the number of sites to be shared) should be minimized while maintaining functionality.

2.7.10 The Mechanics of Fading

Fading is weakening of a radio signal as it passes from the transmitter to the receiver. There are two types of fading:

- Frequency-selective fading (or multipath fading) and
- Mean depression fading (or flat fading)

Fading is caused by atmospheric layering of several types of air ducts, which causes abnormal refraction. Abnormal refraction can cause a condition known as multipath fading, which possess several components, each of which arrives at the receiver at a different time.

Multipath fading (as its name suggests) is generally associated with many different signals reaching the receiver at different times. However there is actually only one signal that really contributes to multipath fading. The signal that contributes to the multipath fading is called the frequency-selective faded signal.

2.7.11 Frequency-Selective Fading

Frequency-selective fading varies much quicker than flat fading. Frequency-selective fading is also called multipath fading. This type of signal fading is the weakening of the transmitted signal due to multiple paths taken by each part of the wave as it spreads out from the transmitter. The different paths each have a different length. The longer the length, the more time it takes for the signal to reach its destination. The differing of times is called the delay. Fading is the result of random amplitude, time delay, and phase differences. This will result in distortions that result in higher BER.

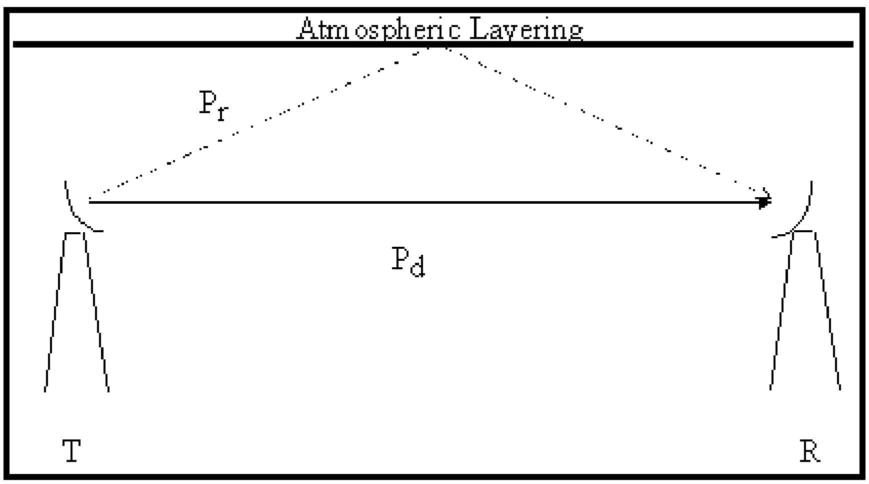


Figure 19, Frequency-Selective Fading

2.7.12 Mean-Depression Fading (or Flat Fading)

The mean-depression component of fading has no frequency properties.

Some causes of flat fading are antenna de-coupling, attenuation due to atmospheric precipitation, and ducting.

There are several ways to classify the conditions that may arise when attempting to propagate a wave through the air. The construction of these diagrams assumed that a constant radio reflective index (RRI) condition exists between the transmitter and the receiver. This is rarely the case, and is a serious limitation to the ray-tracing method.

Some of the sky classifications are:

- Clear Sky Condition:
- Defocusing Event:

- A defocusing event is the beam spreading of the rays of the antenna main lobe. Defocusing is caused by a relatively complex RRI profile within the transmission path. The rays can be divided into two cases:
  - Rays that occur above the horizontal are bent upwards into the sub-refractive region of space.
  - Rays that occur below the horizontal are bent downwards towards the earth.

The ground-based obstruction of path, combined with sub-refractive events, causes severe signal-strength loss.

Shadow zones are also called radio holes and are places in the atmosphere where there is no radio energy present. If the height of a receiver is placed inside a shadow zone, severe signal attenuation may occur. This is called a "high-low" event.

2.7.13 Digital Microwave Communications Systems

The performance of a digital microwave communication system is defined by the bit-error rate (BER). When the bit-error rate exceeds 10^{-3}, the system is considered unusable. The digital system does not degrade gracefully. Degradation occurs in the last few decibels of fading. Frequency-selective fading is the critical factor that determines the performance of a digital system.

2.7.14 Effects of Fading on Microwave Performance

The antenna cross-polarization discrimination will degrade by 1 dB for every decibel of frequency-selective fading present. As a result, when the system suffers from multipath fading, the cross-polarization discrimination (XPD) may not protect against adjacent-channel problems.

XPD ≡ signal transmitted in a given polarization

In shallow multipath fades, the cross-polarization signal is approximately equal to the co-polar signal. The deeper the fade, the greater the loss of XPD.

The loss of XPD under multipath fading conditions can result from several mechanisms. These mechanisms are divided into two categories:

- antenna cross polarizations do not play a role and
- antenna cross polarizations do play a role.

When antenna XPD does not play a role, scattering or reflecting mechanisms produce a cross-polarized wave in addition to the co-polarized wave.

Obviously, the shorter the microwave link, the less fading that will occur. Unfortunately this is not a practical approach. However, a technique called diversity reception will help to reduce fading on MW systems.

There are three types of diversity:

- frequency,
- space, and

- angle.

Each of these diversity schemes aids in the discrimination of the desired signal and performs compensatory techniques for fading.

2.7.15 Route Design Performance Criteria

Error-free seconds (both bursty and severely errored seconds) are used to establish design parameters for the link and the individual hop. The availability and performance budgets are then used to design the path and select the equipment.

A link usually consists of a number of different hops. There are separate requirements that are specified for both individual hops and the end-to-end link. These requirements are referred to as a link budget.

It is common practice to linearly prorate the link budgets to help identify which hops have the worst performance. Also, if a series of prorated hops is studied, the end-to-end budget will be more respected, because the two budgets can be compared.

The longest hops will be most likely to miss the availability and performance objectives set by the linearly subdivided budgets. These criteria in the budgets play a significant role in the spacing of repeaters. The longest hops will usually be involved in most of the problems of the system.

Usually an outage event is defined to be an event with a bit-error rate great than 10^{-3}. There are two conditions that may occur as a result of an outage event. If the outage event occurs for less that 10 seconds, this is considered to be unacceptable performance. If the event occurs for more than 10 seconds, the outage event is classified as unavailable.

Radio systems operating at frequencies below 10 GHz suffer from performance degradations due to multipath fading. Systems operating above 17 GHz are limited by degradations due to rainfall. Systems that lie between 10 GHz and 17 GHz are affected by both rainfall and multipath fading. Outages due to multipath fading usually only occur for less than 10 seconds and fall into the unacceptable category. Rainfall-induced outages usually occur for more than 10 seconds and are categorized as unavailable.

The performance objectives of digital radio systems are expressed in terms of 4 parameters (this is how the impairments are measured):

- Severely errored seconds,
- Errored seconds, and
- Residual bit-error ratio.

There are three types of signal impairments to the channels of the microwave radio system:

- Noise from the input stages of the receiver,
- Interference from co-channel and adjacent-channel transmitters, and
- Intersymbol interference from amplitude and phase distortions of the transmission channel.

2.7.16 Microwave Path Design Basics

Refraction causes the dielectric constant to change with height above the ground. As this happens, the refractive index will also change, and this causes the wave front to bend either up or down. Normally, a vertical dielectric variation is present and will cause the ray to follow a path that has a curvature between that of a straight line and that of the curvature of the Earth.

As the density of the atmosphere increases, the speed of the wave front will decrease. A wave front will be bent towards an atmosphere that is more dense than its own. A dense atmosphere may result from the presence of water vapor, such as is the case with fog. As a result, the wave front is usually bent towards the earth. The bent ray is in the shape of an arc.

To quantify the bending radius, you can compare the radius of the arc to that of the Earth.

To do so, you can define a parameter K:

$$k = \frac{actual\ \ radius\ \ of\ \ ray}{radius\ \ of\ \ earth}$$

The radius *k* helps to classify the atmosphere into three major types of conditions:

- Super Standard refractivity ($k = \infty$),
- Substandard refractivity ($k = 2/3$), and
- Standard refractivity ($k = 4/3$).

These conditions are based upon the way in which the ray will respond to the atmosphere described by the particular *k* factor model.

In a super-standard atmosphere, the ray will approximately follow the curvature of the Earth. In a sub-standard atmosphere, the ray will be bent towards the earth. This is also known as earth bulge because from the ray's perspective the earth appears to be rising. Under normal temperate conditions, the medium standard wave front model is used.

The parameter of interest is the distance defined by the arc tangent of two points and the radius of the earth**.** This is why, to describe a substandard atmosphere, you can say either that the earth bulges or that the ray is bent towards the earth. Either way, the difference between the curvature of the earth and the curvature of the ray remains the same.

Two methods are used to make it easier to analyze the rays:

- Flat Earth Model, Curved Ray (how does the ray respond?).
- Flat Ray Model, Curved Earth (how does the earth appear to respond?).

The *k* factor is a tool used to determine the bending of a beam due to changes in refractivity of the atmosphere. This bent ray is the actual path that the wave takes. Line of sight does not necessarily imply that the ray will follow a line-of-sight path. Deviations will occur due to changes in the refractivity of the atmosphere, and the *k* factor helps one predict what will happen to the wave.

Tompkins County has a number of small lakes and, of course, Cayuga Lake. Bodies of water can greatly impact the *k* factor. The greatest problem with microwave links over bodies of water is not so much a high *k* factor, but rather a fluctuating *k* factor. Thus is a common occurrence with over-the-water microwave links, particularly, in the summer time, with outages due to a fluctuating *k* factor higher than the planned fade margin occurring during some part of the day.

Two rules of thumb follow:

- Odd Fresnel Zone clearance will result in a loss (weakening) that is less than that of free space.
- Even Fresnel Zone clearance will result in a loss of signal that is more than that of free space.

The difference in the losses between even and odd Fresnel Zones is due to the difference in the phase of the signal in the two regions. When the signal is normally reflected, it undergoes a 180-degree phase delay with respect to the incident wave front. If the reflector is in the first Fresnel zone, the wave will be delayed by an additional $\frac{\lambda}{2}$, for a total delay of λ.

2.7.17 Path Reflections

Antennas at different elevations will have a reflecting angle vertex closer to the lower antenna. This may cause significant fading.

Antenna heights may be moved so that the point of reflection moves to a better surface, to decrease the amount of reflection.

Moving the point of reflection may be beneficial in that:

- the point may be moved so as to block the reflected ray path,
- the point may be moved to a rougher surface, or
- the point may be moved away from an over-the-water link.

The rougher the surface, the more diffuse the reflected ray and the less concentrated the reflected energy. Surfaces such as water will reflect energy very much.

The magnitude of the reflection coefficient increases as the angle of incidence decreases. As a result, waves of short length and a high height will be less affected by path reflections than antennas at low heights.

There is a 180-degree phase reversal at the point of reflection.

The magnitude of the reflection coefficient of a vertically polarized wave is much less than that of a horizontally polarized wave.

The phase change (or lag) at the point of reflection for a vertically polarized wave is significantly affected at low grazing angles, as compared to 180-degree phase reversal for a horizontally polarized wave.

Refractive conditions will cause the wave to bow and will affect the location of the point of reflection and may cause it to move.

It is a good practice to determine the practical limit of travel of the reflection point. To do so, you can use two extreme *k* values:

$$k = \infty$$

$$k = grazing\ \ value$$

The grazing value of *k* will put the path of the ray just above the ground.

2.7.18 Power Link Budget

A path-power budget is an itemized list of all system losses and gains from one end of the path to the other.

The effective radiated power (ERP) must have two factors subtracted from it: the free space path loss (FSPL) and the atmospheric loss (due mostly to the presence of oxygen and water).

Each receiver has a noise-threshold specification, which is actually the sensitivity of the receiver.

This threshold is the lowest receiver signal level at which the receiver will be considered unusable.

Most digital microwave receiver systems use a bit-error rate to analyze the recovered data, usually when the BER of the data exceeds 10^{-3}. After this point, the condition of the receiver is said to be in the outage point.

When the BER exceeds 10^{-6}, the condition of the receiver is termed non-operative.

In analog microwave systems, the fade margin is defined as the difference between the receiver threshold value and the received-signal level that is applied to the receiver. In other words, a safety margin of excess signal must exist before the receiver becomes unusable due to noise.

On digital microwave systems, the fade margin is called the flat or thermal fade margin (TFM).

Other digital parameters that are used are:

- dispersive fade margin,
- adjacent-channel-interference fade margin, and
- external-interference fade margin.

The sum total effect of these parameters is called the composite fade margin.

A typical digital or analog receiver threshold is –70 dBm to –85 dBm.

Microwave receivers have a specified range over which they should properly detect and decode information. As a result, there is a minimum (as well as a maximum) signal input level that can be applied to the receiver input. Any signal input lower than the minimum or greater than the maximum will result in distortion and data loss.

It is impractical to think that significantly raising the signal energy will create a large fade margin and solve the problem of the presence of noise.

Upfading can also occur on a microwave system. During upfading, the microwave system experiences a huge increase in signal strength. The upfading condition usually occurs immediately following severe multipath activity. Upfading is caused by the lens effect of the atmosphere.

There should be a margin of at least 10 dB between normal path received signal level (RSL) and the receivers upper RF input limit.

A typical flat-fade margin ranges from 40 to 50 dB.

2.7.19 Path Reliability

Reliability (or availability) is a percentage of time that the link will operate without outage (when the outage is due to propagation effects). For LOS, this usually occurs about 99.999% of the time.

The opposite parameter is unavailability or outage. Quantitatively, the unavailability can be found by 100 minus availability. A normal time reference is one year.

A significant factor that affects path reliability is rain attenuation. This is especially true for signals that are greater than 10 GHz. Tompkins County microwave links are currently all at about 2 GHz.

There are generally two factors that enter into the effect that rain has on radio-wave propagation:

- Intensity of the rain and
- Percentage of the radio path that lies within the rain.

Rain-rate statistics vary with geographic location and can be found through the National Weather Bureau.

Noise Threshold + Fade Margin = nominal receive level into the receiver.

Transmitter output - Desired Received Signal Level = Maximum allowable net path loss.

When path distance and antenna height are both known, total loss may be calculated:

FSPL + Atmospheric Loss + Hardware Loss = Total Loss

Total Loss > maximum allowable net path loss.

Total Loss - maximum allowable net path loss = Amount of Additional Gain needed.

The additional gain can be added by adjusting the combined gains of the antenna transmitter and receivers. The gains will depend on the diameters of the antennas.

A parabolic dish antenna will have typical gain efficiencies of 55% to 65%. The range of gain for microwave antennas goes from 30 and 50 dB.

If reliability standards still are not met, diversity methods may be used.

An example of a diversity method is the addition of separate receive antenna (and receiver).

The diversity antennas are usually mounted on the same vertical tower separated by a distance. This creates an actual separate microwave path.

Receiver sensing equipment then switches off the receiver that contains the weaker signal.

Space diversity significantly increases cost due to the need for additional equipment such as:

- antenna
- receiver.

Another cost that makes space diversity so expensive is the need for adjustments to be made on the towers for wind and ice loading.

Adequate spacing between diversity antennas will make the correlation between the signals small. This leads to better reliability.

The more the number of antennas, the smaller the probability that all diversity antennas will experience fading at the same time. This increases reliability.

Recommended maximums for site spacing are:

- 40 miles 2 GHz
- 35 miles 4 GHz
- 25 miles 6 GHz
- 15 miles 11 GHz

There are generally two different types of frequency diversity:

- in band and
- cross band.

In-band frequency diversity is done in one band. Cross-band diversity is done across two bands. Cross-band diversity is used to transmit the same information to separate receivers.

Increased reliability is achieved from the reduced chances of fading occurring on two frequencies instead of one.

Space diversity produces greater improvements than any other type of diversity technique. However, diversity reception does not provide improvement against rain attenuation.

Another type of diversity used is angle diversity. It is used to catch more of the incoming signal. Angle diversity does little to improve multipath and reflective conditions. Hybrid diversity is using both frequency and space diversity at the same time. The practice of this technique can be difficult when atmospheric conditions are changing. This can be a solution to mitigating multipath when space diversity can not be implemented (e.g., due to regulatory problems or ethics).

2.7.20 Licensing

Microwave systems require FCC licensing under part 101 of the Rules and Regulations. Frequency coordination is required, and FCC Application Form 601 must be filled out. There is a class of microwave systems that do not requiring licensing by the Commission under part 15 of the Rules. These unlicensed systems usually use spread-spectrum modulation, which spreads the power level over a large bandwidth. These modulations are less susceptible to "co-channel" interference, and it is felt that they can be applied without coordination. However, they are generally considered unacceptable to public-safety applications because they are uncoordinated and therefore inherently vulnerable. They are used only in short-link hops where the criticality of the link is not great.

2.8 Application of Wireless to the Public-Safety/Service Client

Tompkins County public-safety radio users are similar to all public-safety users in their basic or fundamental radio system requirements. These high-level requirements are detailed below in Figure 20.

Figure 20, Fundamental Requirements of Public Safety LMR

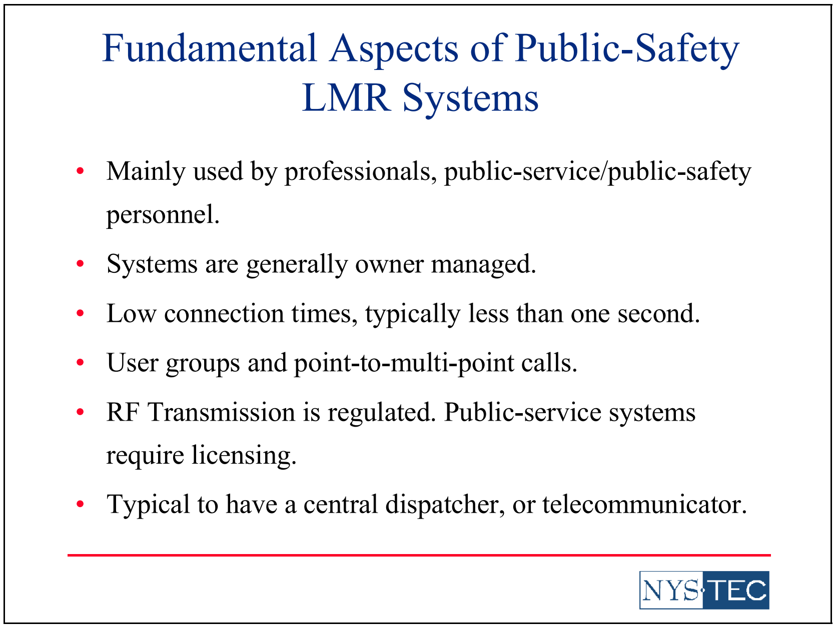


Figure 21, Fundamental Aspects of Public-Safety LMR Systems

LMR communications have continually adapted to the changing demands of modern society. As the number of users and their needs have increased, radio manufacturers have followed suit by pushing the envelope of "current" technology. To illustrate how radio communications have changed, two generic system examples follow.

These examples contrast past and present technologies: the first (Figure 22) shows a system using older legacy hardware; the second (Figure 23) shows a system employing some newer technologies.

Yesterday's radio network could meet the requirements of a city's municipal department based upon the "technology of the day." Typically, an older radio system used a few channels to dispatch units in response to a specific incident. Such a system might have had a single base station tied to a central dispatch office, handling calls on a first-come, first-served basis. Today, such systems are referred to as conventional radio systems. Figure 22 illustrates this type of network.

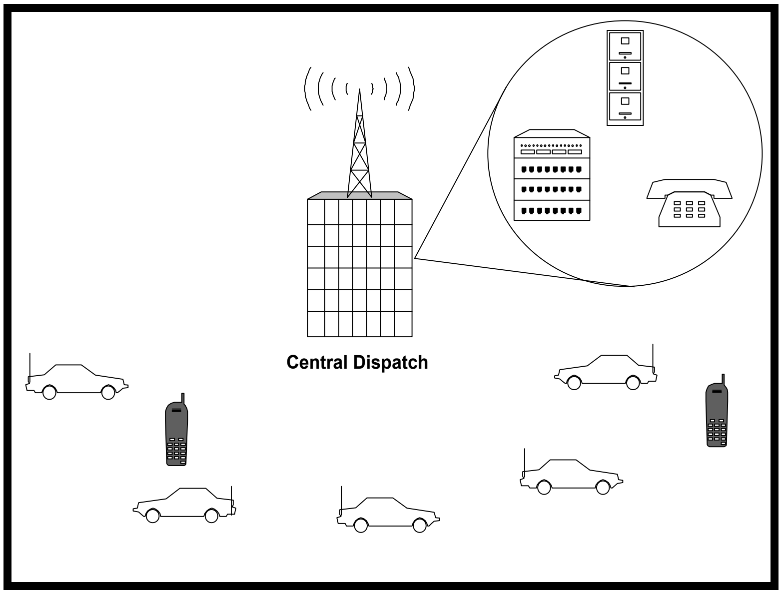


Figure 22, Simple Conventional System

As Figure 22 shows, the radio hardware was minimal. Dispatchers could be alerted to an emergency by a unit in the field or by a telephone call to an operator assigned to handle calls. Data and record retrieval was handled through simple file storage. Since only one channel was available to communicate with HQ serially, a problem requiring parallel/overlapping access could potentially escalate into a serious crisis. The only way a conventional LMR system could provide parallel/overlapping access was for some units to switch to another available channel (if the system had another channel available) and for the users and dispatcher to coordinate among themselves. The other available channel used in this manner for coordination is often called a tactical or local channel. However, reliance on this type of channel use could sever the lines of command, control, and communication — resulting in the loss of field-unit control. Ultimately, the safety of personnel and the lives of civilians could be put at risk. A solution was desperately needed.

Needs tend to drive change, and markets tend to respond in kind. As a result, many current public-safety/service communications systems have advanced greatly. Many new technologies are being utilized — to the advantage of radio customers and citizens alike. Information formerly handled on paper has been supplemented electronically. Today's police investigators need access to national criminal databases, warrants, arrest information, fingerprint IDs, and many other resources. Public-works applications may require access to GISs for mapping routes or for generating detailed maps of work locations. For data to be useful, one must be able to access it quickly.

A modern system looks like the one depicted in Figure 23.

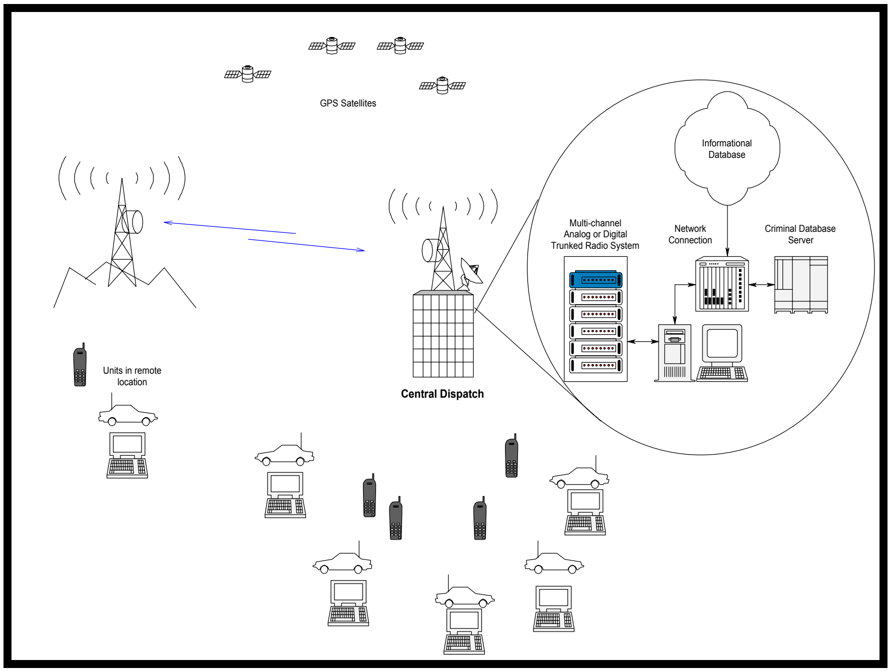


Figure 23, Modern Public-Safety Communications System

In order to handle the increased radio communications traffic loading, multi-channel trunked radio systems are increasingly replacing their conventional, single-channel predecessors. Mobile data terminals (MDTs) are also being incorporated to enable units in the field to access records and databases. If extended coverage to outlying or remote areas is necessary, a separate, trunked site can be remotely linked to network control by point-to-point microwave radio or by fiber-optic or copper cables.

Further, global positioning system (GPS) satellites can be used to get precise location information on units in the field. This information can then be integrated within a computer-aided dispatch (CAD) system to monitor an operator's status. By fusing many types of data, CAD can put a multitude of information at the dispatcher's disposal.

Tompkins County will have to seriously consider digital trunked radio with microwave as the site link media. Digital trunked technology will give the County constant voice and data coverage and features that accomplish the fundamental requirements discussed above.

Simulcasting is also a very real possibility. The County does not face a serious capacity problem and will most likely not for some time into the future. In Tompkins County, achieving the required coverage will be the greater challenge. Simulcast operations allow for more effective spectrum usage over a geographic area. Simulcasting could make the most efficient use of the limited 800-MHz spectrum available to the County (10 pairs), and help achieve in-building coverage in Ithaca.

3. Proprietary Trunked Systems

This section reviews the various major manufacturers that have trunked systems applicable to public-safety use today. The following trunked systems are proprietary or systems that represent complete systems solutions for a manufacturer. These systems and their components — from handsets and switches to repeaters — will only work with equipment from the manufacturer or their partner manufacturers.

These various system options are available today. This section discusses the use of enhanced specialized mobile radio (ESMR) systems, or digital trunked systems. The operation of trunked systems was reviewed in the previous section. Tompkins County has considered the use of modern digital trunked systems for its public safety LMR in the past. A trunked system is a mobile radio network that can be utilized for both voice and data service and that still retains its LMR underpinning.

3.1 OpenSky

OpenSky is a wireless data solution developed by AMP originally for Federal Express use for its urban operations. Federal Express required a new wireless mobile data system that would provide four times the message data of its previous system. In addition, Federal Express also needed occasional voice communications to handle exceptions that would not be conveyed over the data system.

A partnering with Federal Express allowed AMP to develop a wireless data and wide-area network solution that is reviewed here. Most systems deployed today are *voice* systems that support data, whereas OpenSky is a wireless *data* system based on data communications technology. The system currently supports public-safety 800-MHz channels and cellular AMPS channels[16]. The Commonwealth of Pennsylvania is currently deploying a statewide OpenSky system.

OpenSky is an 800-MHz system that utilizes TDMA with two time slots to support both voice and data services. The two time slots can be used for both voice and data simultaneously or can be aggregated to support 19.2-kbps throughput on a 25-kHz channel. The two time slots can be split to enable full duplex voice operation or can provide a single simplex digital voice channel and a single data channel with 9.6-kbps data throughput.

What is interesting about this for Tompkins County is that, under a hybrid network scenario, the urban agencies, which may have higher data needs, could use OpenSky radios for data. This would take some of the load off the voice system and increase capacity. Also OpenSky could be used where some of the carriers have Cellular Digital Packet Data (CDPD) channels on their network.

The benefit to Tompkins County may be in the openness of this system. Much of information technology is moving toward TCP/IP as the protocol for wireline networks to communicate. The corresponding wireless data protocol is CDPD, which uses TCP/IP as the application layer interface. CDPD has had very slow deployment, and it remains to be seen whether the cellular

[16] AMP has noted that it intends to implement Channels 60 - 69 when the FCC issues specifications for those channels.

companies will continue its anemic expansion or will change to another standard that works within digital cellular. However, advantages may well exist for using this technology in PLMR[17] applications. The disadvantage of all this is that CDPD is a system that only analog cellular carriers provide. In the State of New York, CDPD is not available north or west of Westchester County. Given that cellular carriers are much more interested in developing digital systems, it is highly unlikely that a cellular carrier would ever offer CDPD in Tompkins County.

The OpenSky private network protocol is an adaptation of CDPD that will run on a PLMR SMR[18]. In this sense, OpenSky can be like a privately owned CDPD system. AMP claims to achieve 19.2 kbps in a 25-kHz channel with voice using a AMBE[19] vocoder,[20] then transmitting data packets through the network using TDMA access protocol to the PLMR. The OpenSky private-network protocol is a trunking protocol that is proprietary. This is about the only proprietary aspect of this system.

3.1.1 OpenSky System Design

The OpenSky radio interfaces with the vehicle's laptop via an RS-232 connection. OpenSky runs 19.2 kbps at 25-kHz bandwidth or 9.2 kbps at 12.4-kHz bandwidth. A proprietary base station is required to operate in PLMR. The base station located at the radio site uses a leased 28.8-kbps (V.34) modem to communicate back to the dispatch console over an Ethernet LAN and to an OpenSky MD-IS[21]. OpenSky refers to this as the MIS, or Mobile Intermediate System, which is made up of a Sun Microsystems Sparc workstation running software for a voice and data router.

Within dispatch, a conventional Ethernet LAN connects the MD-IS and most all the peripherals. Data is then routed to the MDT (mobile data terminal) and RMS (records-management system) host computer, and the voice is routed to the dispatcher. The voice router controls the voice talk group assignments.

The OpenSky network protocol is a TDMA proprietary protocol that gives voice trunking functionality. Voice is digitized at 5.9 kbps and transmitted as data packets. This type of access control gives the system (with 25-kHz bandwidth) two simultaneous voice channels, or one voice channel with a 9.6-kbps data-ready channel.

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[17] PLMR, Private Land Mobile Radio.
[18] SMR, Specialized Mobile Radio (trunking operation).
[19] AMBE, advanced multiband excitation.
[20] Similar to APCO's Project 25 IMBE vocoder.
[21] Mobile Data-Intermediate System. This is part of the CDPD architecture as well.

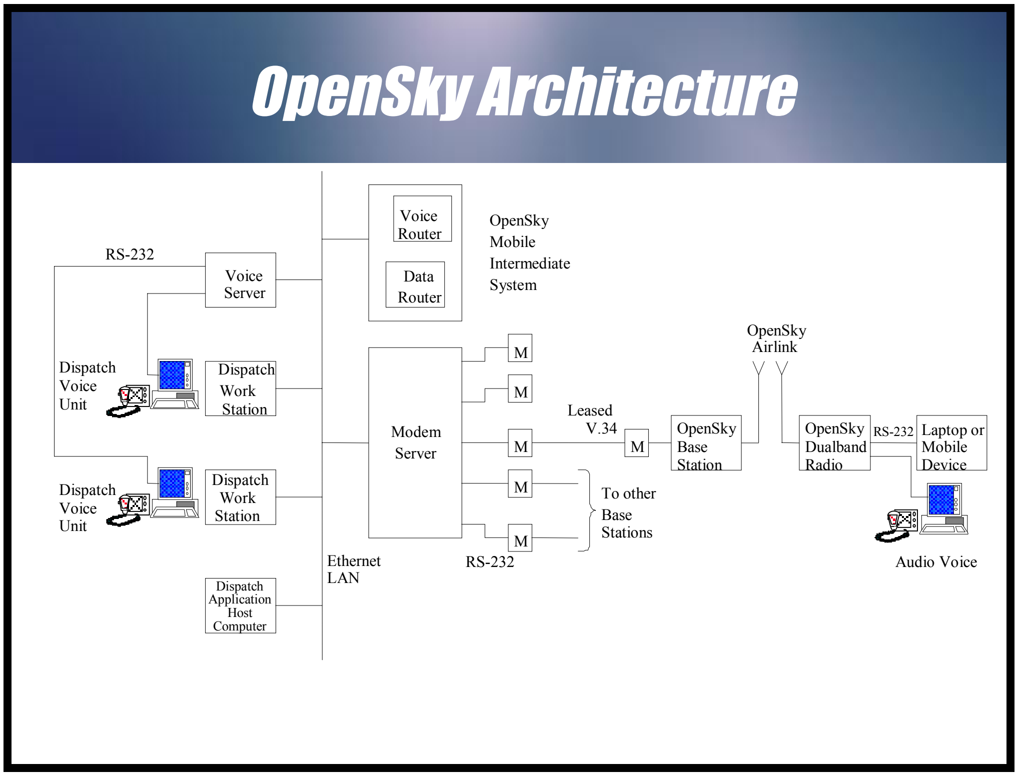

Figure 24, OpenSky Architecture

A point of interest in the OpenSky concept is the drive in the design to integrate many industry-standard components. Internet protocols like TCP/IP and UDP/IP (as well as CDPD architecture) are used in the design. The MD-IS system has been thoroughly tested and has been extensively deployed. Again, the future of CDPD as a carrier service is in question; however, with the OpenSky digital use of CDPD, the application in a PLMR network makes it a serious contender in technologies that contend for voice and data applications.

Further, the hardware components used in an OpenSky operation are readily available and reliable. Hardware components such as workstations and routers are common to the system and can be purchased from multiple sources. Only the radios (both portable and mobile), the base stations, and the voice codecs for the dispatch positions are proprietary from AMP.

3.1.2 System Features

- Architecture that is derived from CDPD and provides a private implementation of CDPD on the customer's PLMR channels.
- OpenSky uses industry-standard Internet protocols to provide a TCP/IP (or UDP/IP) interface to the application software.
- Throughput is 19.2 kbps in a 25-kHz bandwidth private land mobile channel, or 9.6 kbps in a 12.5-kHz bandwidth channel.
- OpenSky provides integration of data messaging and digital voice, using 5.9 kbps advanced multiband excitation (AMBE) digital voice.

- Each radio has an Internet Protocol (IP) address.
- The mobile radio supports both the 800-MHz private land-mobile band and the AMPS cellular band.
- OpenSky supports digital voice transmission trunking and message trunking.
- A single radio handles both voice and data.
- AMBE vocoder.
- The system provides support of both long message transfers and short messages such as automatic vehicle locator (AVL).
- The mobile radio is available with an internal global positioning system (GPS) AVL.
- The system supports differential GPS with the differential updates being periodically transmitted to the mobile radios over the customer's private land-mobile channel using broadcast messages.
- Vehicular Repeater Function. The Vehicular Repeater is intended to provide local area coverage for portable radios. Conceptually it consists of two full-duplex mobile radios connected back to back. The first radio appears as a base station to the portable devices, creating a small local radio cell. The second radio functions similar to a normal OpenSky mobile radio, forwarding messages from the local radio cell to a fixed base station.
- Ability to maintain high throughput under high loading with an advanced channel-access arbitration protocol.
- Grouping functions.
- Dynamic reconfiguration of groups.
- On-system roaming.
- Over-the-air reprogramming of subscriber units.
- Embedded trunking control (a time slot) eliminates need of a dedicated control channel.

The key system components are identified in Table 5.

Table 5, OpenSky Network Components

Component	Description
Dispatch Voice Unit	Open Sky radio that is connected to the terminal server using a serial line internet protocol (SLIP) interface.
Base Station	Full duplex base station. Can act as a repeater for mobiles.
Mobile Data Terminal	Laptop or similar device that connects to radio unit through an RS-232 interface.
Mobile Radio	Used to communicate over the wireless network. Has provisions for • Microphone, • Data input and output, • GPS, • Logic inputs for emergency vehicles
Router	Used to interconnect various network aspects to the radio system that includes: • Routers, • Ethernet switches, • Servers, etc.
Terminal Server	An off-the-shelf device to provide connectivity to asynchronous devices such as dispatch voice unit (DVU) and digital service unit (DSU) equipment.
OpenSky Server	The OpenSky server running the UNIX operating system that runs: • Mobile Data Intermediate System (MDIS) to perform unit validation, data routing, and tracking of subscriber units. • Voice Network Interface Controller (VNIC) used for digital voice routing.
Digital Service Unit	Connects the base station to the network IP backbone. Typically runs at • 56 kbps or as • part of a microwave network.
DSU	Links the DSU and base station together.

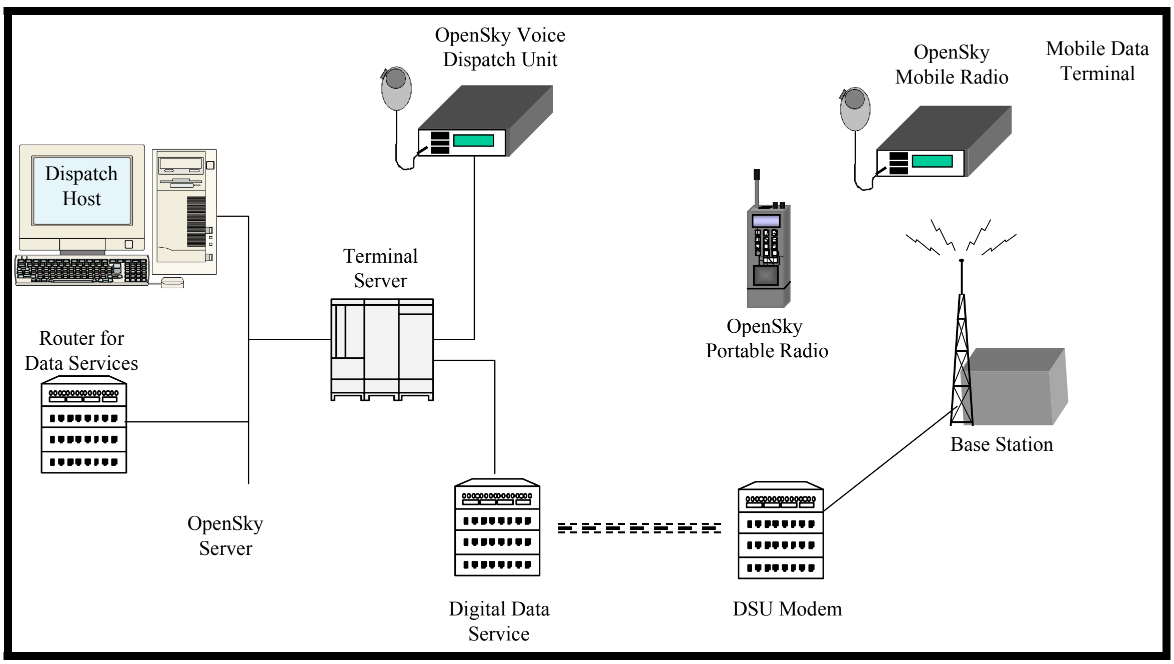

Figure 25, OpenSky System Components

The OpenSky system fits many applications that need both voice and data capability in a single integrated package. The system provides solutions to meet a wide variety of needs in Public Safety[22].

3.2 EDACS

The manufacturer of EDACS (the Enhanced Digital Access Communications System) is ComNet Ericsson Critical Radio Systems, headquartered in Lynchburg VA. EDACS is a trunking system that is available in both analog and digital air interfaces. This system is based on a number of propriety interfaces and protocols. EDACS is used in trunked repeater systems that include wide-area simulcast operation. ComNet Ericsson has stated recently that it will concentrate on and manufacture more radio system products tailored toward small public-safety agencies around the world.

This manufacturer started as the land-mobile manufacturing operation for RCA. RCA sold this sector of its business to General Electric Co. General Electric then sold this sector to Ericsson Inc, which recently (January 2000) sold this business to ComNet, which re-named it ComNet Ericsson Critical Radio Systems Inc. EDACS equipment is ComNet Ericsson's primary line of LMR systems designed for the public-safety market. The Digital Vocoder used in EDACS is proprietary and known as the Aegis Vocoder.

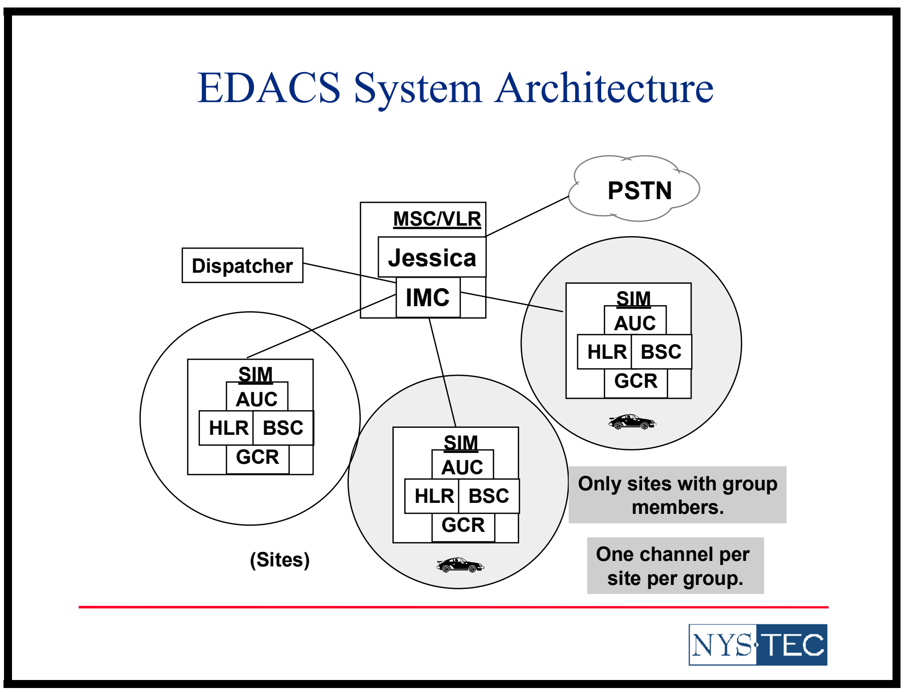

Figure 26, EDACS System Architecture

[22] All of the information and diagrams depicting the OpenSky system presented in this section were obtained or adapted from AMP wireless's product information appearing on its web site http://www.macom.com/opensky/.

3.2.1 EDACS Features and Functions

EDACS can support analog and digital modulation — in both 25- and 12.5-kHz bandwidths — in the same system. The access type is FDMA. It is available in VHF, UHF, and 800/900-MHz bands. This system does run in simulcast and, in New York State, the New York State Police uses analog and digital EDACS simulcast of its Troop NYC.[23] This system is capable of handoff in the multi-site environment. The air interface is proprietary. ComNet Ericsson Critical Radio Systems Inc. is not now a manufacturer of Project 25 equipment. ComNet Ericsson is a participant in the ANSI-102 standards process.

3.3 SmartNet

Motorola has seven different trunked radio product lines — StartSite Express, StartSite, SmartWorks, SMARTNET, Simulcast, SmartZone, and SmartZone OmniLink — to meet a wide range of needs. Table 6 summarizes their features.

Table 6, Motorola Trunked Radio System Features

System	Channels per Site	Sites per System	Analog	Digital	Number of Talk Groups	APCO Compliance[24]
StartSite Express	5	1	✓	-	n/a	no
StartSite	5	1	✓	-	n/a	no
SmartWorks	7	1	✓	-	2000	16
SMARTNET	28	1	✓	✓	4000	16, 25
Simulcast	28	10	✓	-	> 4000	16, 25
SmartZone	28	48[25]	✓	✓	n/a	16, 25
SmartZone OmniLink	28	192[26]	✓	✓	n/a	16

Motorola trunked radio systems utilize a dedicated control-channel system-access method. Therefore, the number of usable channels per site will be at least one less than the maximum number specified. The channel-access method utilized by all products is FDMA. All of Motorola's product offerings that are capable of digital voice will support analog operation as well. A wide range of encryption options is available for these systems.

Table 7 presents the frequency bands in which Motorola's trunked systems can currently operate.

Table 7, Motorola System Operating Bands

System	Frequency Bands
StartSite Express	800 MHz
StartSite	800 MHz
SmartWorks	800 MHz
SMARTNET	VHF, UHF, 800 and 900 MHz
Simulcast	VHF, UHF, 800 and 900 MHz
SmartZone	VHF, UHF, 800 and 900 MHz
SmartZone OmniLink	VHF, UHF, 800 and 900 MHz

---

[23] This system was built by the NYSP as the Metro 21 Project in 1994.
[24] APCO Certification 16 (trunking Public Safety control reliability) or APCO 25 (ANSI 102 Standards).
[25] Currently under re-design for greater site capacity.
[26] *Ibid*.

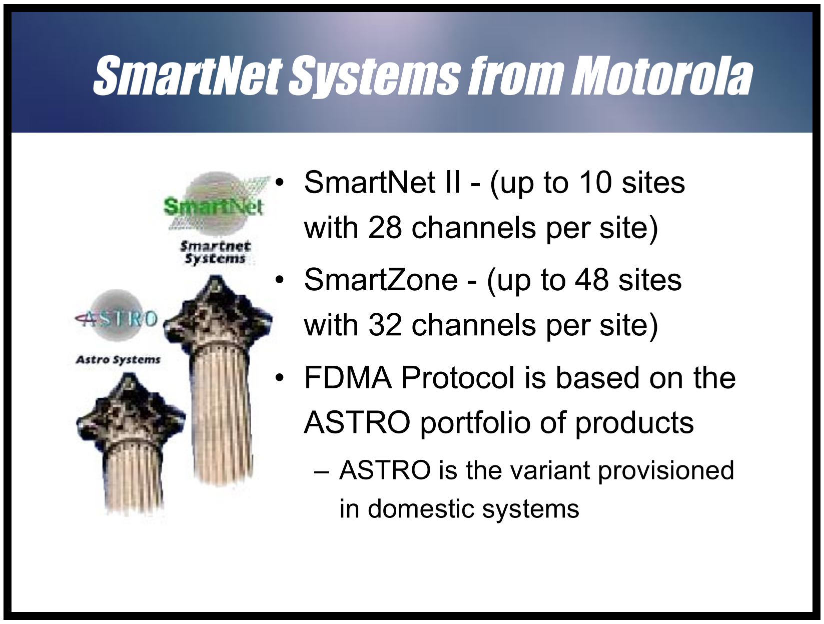

Figure 27, SmartNet Domestic Offerings from Motorola

The StartSite Xpress and StartSite products are considered to be basic single-site trunked radio systems. They provide the basic benefits that analog voice trunking has to offer. The next systems in the product line, SmartWorks and SMARTNET II+, include even more robust trunking features. Both are intended for single-site operation. SMARTNET II+ supports analog and/or digital voice. For larger geographical areas, the Simulcast trunked radio network is a solution that provides the features of an analog-only SMARTNET II+ system. Simulcast utilizes a set of common frequencies to extend the coverage. This feature also allows the system to support a greater number of radios for a given number of frequencies.

For large-scale trunking, the SmartZone and (on a grand scale) SmartZone OmniLink systems provide the greatest amount of options and features. In a SmartZone network, the conventional radios can be integrated into the trunked system. This is a handy feature for migration from a conventional to a trunked system. With the OmniLink feature, Motorola has added a distributed access architecture that can link up to four SmartZone systems together to form one network capable of 192 sites. This system is available in four bands: VHF, UHF, 800 MHz, and 900 MHz.

Motorola's analog and digital radios can support encryption. Transcrypt Corporation manufactures multiprotocol radios for Motorola's SmartNet and SmartZone trunk radio systems. These radios support the DES, DES-XL, APCO 25 DES, DVP (Digital Voice Protection), and DVP-XL encryption identified as the SecurNet (Motorola trade mark) option[16].

3.4 iDEN

One of the premier Enhanced Specialized Mobile Radio (ESMR) systems is the all-digital Motorola iDEN system, operated in the U.S. exclusively by NEXTEL. iDEN operates in the 806-821 MHz and 851-861 MHz bands. The access method used for iDEN is TDMA, using 6 time slots in a 25-kHz channel. The modulation utilized is Quadrature amplitude modulation (QAM), which permits a spectrally efficient use of the available 25-kHz channels. To maintain a high quality of voice service, iDEN employs the vector sum excited linear prediction (VSELP) voice-coding algorithm. The raw data rate of the 25-kHz-wide channel is 64 kbps. Key features of the iDEN system are:

- Phone service,
- 9.6-kbps data,
- Messaging service,
- Group calling, and
- Private calling.

Figure 22 illustrates the key components of an iDEN system.

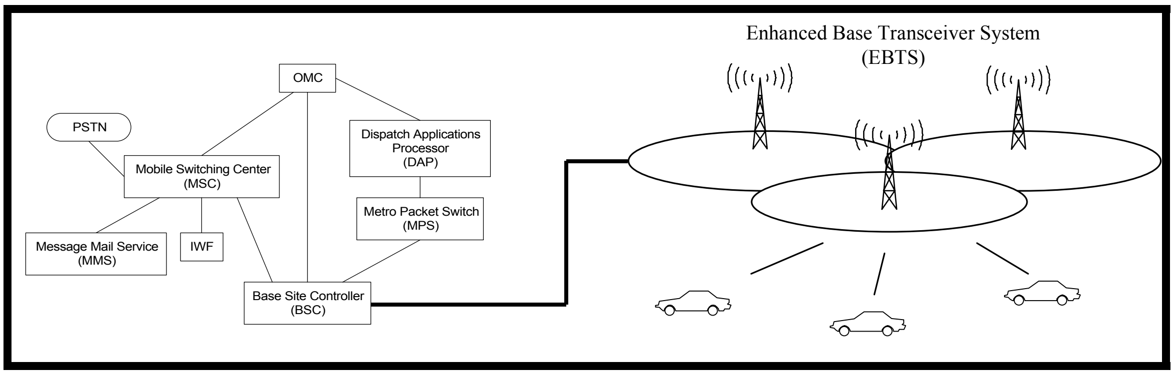

Figure 28, iDEN System Components

The dispatch audio processor (DAP) is used to perform overall system command and control for all dispatch communications. As soon as a subscriber unit activates its radio, an identification is transmitted to the DAP, notifying the system. To provide connectivity with a PSTN network, the mobile switching center handles the setting up and routing of all telephone calls to terminals in the system. Messaging functions are provided in the iDEN system through the message mail service (MMS). The MMS provides the subscriber with store-forward and delivery of alphanumeric text messages.

Single-subscriber to many-subscriber switching is performed among the metro packet switch (MPS) and the enhanced base transceiver system (EBTS) and the DAP for processing voice and dispatch functions. The MPS provides features that include:

- Wide-area dispatch,
- location of subscribers on the system, and
- dynamic replication and distribution of voice packets.

The network element that is used to link the portable and mobile subscriber terminals to the system is the enhanced base transceiver system (EBTS). The EBTS is a cell site that has provisions to support both telephone and data services. The EBTS provides access to:

- the PSTN,
- Dispatch,
- Text messaging, and
- Data.

The base site controller (BSC) is used to control site services for all units accessing the system. The BSC links and controls the EBTS and MSC elements in an iDEN network. A BSC also performs the necessary coding and decoding of voice calls to PSTN networks.[27]

[27] Motorola iDEN product information, www.mot.com/LMPS/iDEN.

4. STANDARDIZED TRUNKED SYSTEMS

This section reviews the various major manufacturers that have trunked systems applicable to public-safety use today. These trunked systems have gone through a process making them open-standards systems. These systems represent systems solutions from multiple manufacturers. The components of these systems — i.e., handsets, switches, and repeaters — will work with equipment from the manufacturers participating in the standards process. The two LMR systems discussed are Project 25[28]and TETRA[29]. These are open-standards systems that evolved out of different standards processes. The sections on these individual systems detail the process that they underwent to become standardized.

This section discusses the use of enhanced specialized mobile radio (ESMR) systems, or digital trunked systems. The operation of trunked systems was reviewed in the previous section. Tompkins County has considered the use of modern digital trunked systems for its public-safety LMR in the past. A trunked system is a mobile radio network that can be utilized for both voice and data service and that still retains its LMR underpinning.

4.1 Standards Refinement and Convergence

Both the Project 25 and TETRA suites of standards are continually under development and refinement; of these two, TETRA is the more mature. It is also clear that Motorola's position is that it wants to block TETRA's entrance into the U.S., unless it becomes a U.S. standard. For this reason, the TETRA Memorandum of Understanding (MoU) group has decided to include TETRA in its offering as one of the possible solutions for a Project 25 Phase II technology. This implies that a Project 25 and TETRA convergence might occur, as illustrated in Figure 29.

A Project 25/TETRA convergence would be a beneficial progression, since TETRA currently meets the spectral efficiency required of a Project 25 Phase II technology and is likely to be mandated by the FCC for 700-MHz operation. However, also note from Figure 29 that TETRA is not the only possible Project 25 Phase II technology. It stands beside an FDMA-based technology proposed by Motorola and another TDMA-based solution proposed by Ericsson. Furthermore, the level of backward compatibility that TETRA must provide to Phase I Project 25 systems is yet to be decided and could be substantial. At a minimum, TETRA would have to include a dual-mode capability into its subscriber radios. These modifications would likely increase the price relative to standard TETRA equipment, and might possibly lower the number of vendors willing to offer this TETRA/Project 25 Phase II-compatible equipment. In reality, TETRA manufacturers will need to include some of these capabilities in order to offer equipment within the U.S. 700-MHz band. Therefore, many TETRA vendors are working on the design tradeoffs necessary to deal with these issues.

[28] American National Standards Institute Standards (ANSI) process number 102.
[29] TETRA: Terrestrial Trunked Radio.

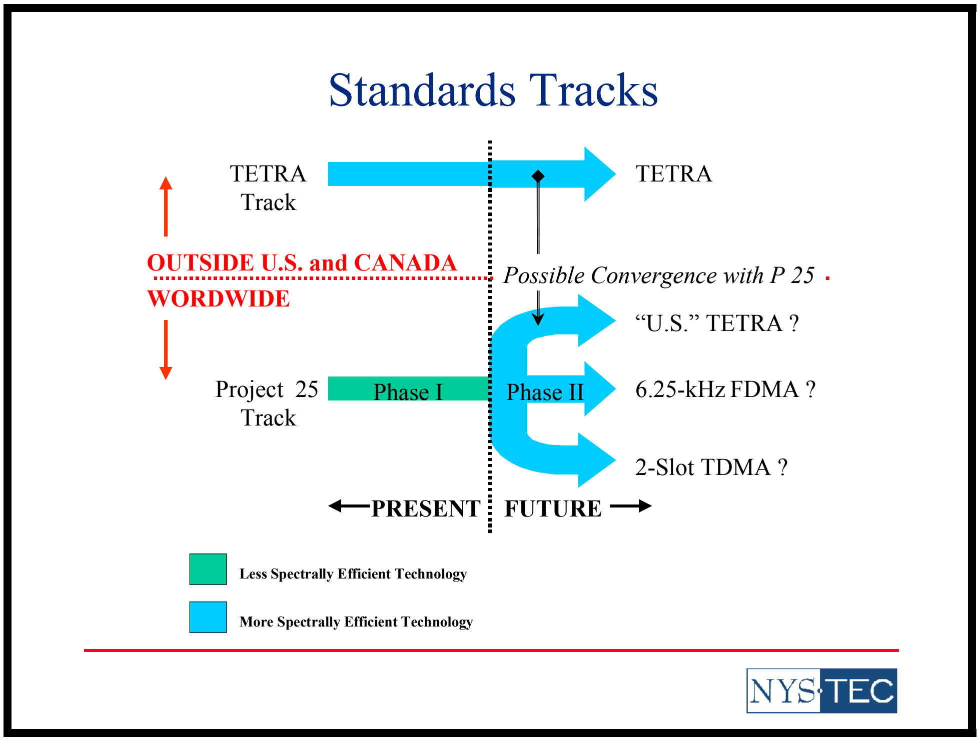

Figure 29, Domestic and International Standards Tracks

4.2 APCO Project 25

The accepted public-safety digital radio standard within the United States is APCO Project 25 (P 25). Project 25 is actually a suite of standards that define interfaces and technologies for public-safety radio communications equipment. Involved with the development of these standards are many groups and individual agencies, including public-safety organizations such as the Association of Public Safety Communications Officials (APCO), Federal agencies, and vendors such as Motorola and E. F. Johnson. The Telecommunications Industry Association (TIA) serves as the standards-development organization, and operates under the open-forum principles of the American National Standards Institute (ANSI). Project 25 standards documents are developed by TIA engineering committees based upon user needs, approved by the APCO Project 25 steering committee, and submitted for public ballot. The final documents are published as TIA and ANSI standards. These are published under TIA as Telecommunications Systems Bulletin (TSB) 102-A.[30] The features and functions are shown in Figure 30.

[30] TIA Published Document Series 102, June 2000.

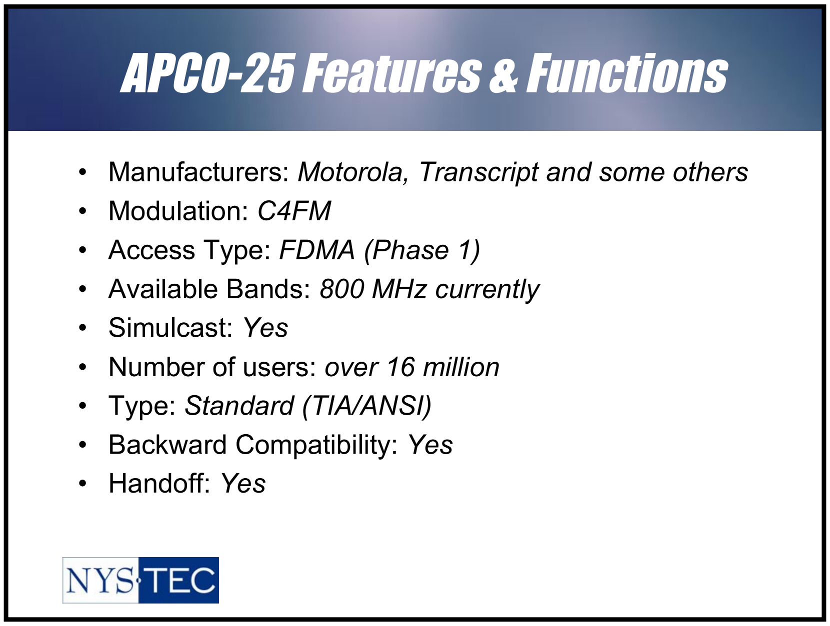

Figure 30, APCO 25 Features & Functions

The NYSTEC/SWN project team has been deeply involved with events and discussions relating to Project 25 standards development and, in fact, Robert F. Schlieman of the SWN Project Office is a member of the Project 25 Steering Committee.

The SWN Office and NYSTEC have also had extensive exposure to Project 25 equipment and technologies at APCO and PSWN (Public Safety Wireless Network) events, have made numerous presentations, and have engaged in many meetings with Project 25 vendors regarding technologies, timelines, and relevant design issues.

4.2.1 History

As shown in Figure 31, the vision of APCO Project 25 began in Washington DC in December 1989, when a large group of users, vendors, and others met to discuss “Public Safety Digital Radio.” This group was led by an organization called Open Architecture Radios for Public Safety (OARPS), which had previously tried unsuccessfully to standardize trunking protocols for analog radio systems. After much discussion, it was decided that the timing was right to develop standards for digital radio systems, and the Project 25 coalition was formed. The bulk of the Project 25 Phase I standards were finalized in 1995. The remaining Phase I standards, along with additional Phase II technologies and standards, are still under development and consideration by the Project 25 steering committee.

Figure 31, APCO 25 Background

4.2.2 Technology

Project-25 is a standards suite that is still evolving. The most mature portions of the Project 25 standards define equipment that is available and deployed today. This equipment falls under "Phase I" of the Project 25 track, and offers a spectral efficiency of two voice paths per 25 kHz of bandwidth. It is a digital Frequency Division Multiple Access (FDMA) based technology that occupies 12.5 kHz of bandwidth. Therefore, it can only allow one voice or data communication at a time for a given radio channel resource.

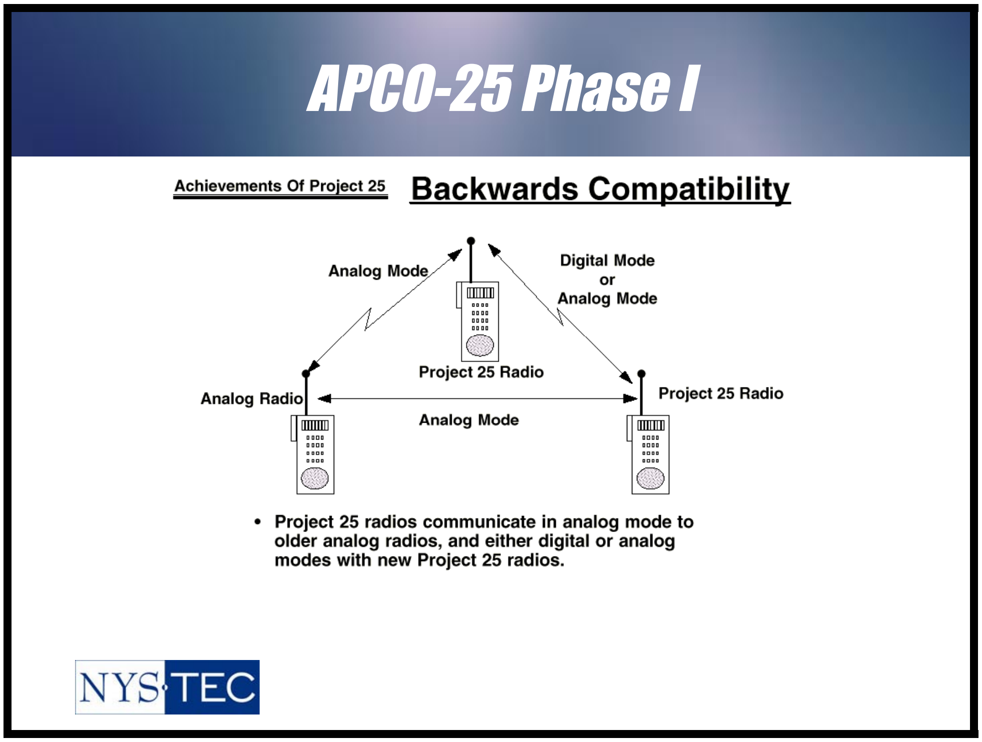

Figure 32, APCO-25, Phase I

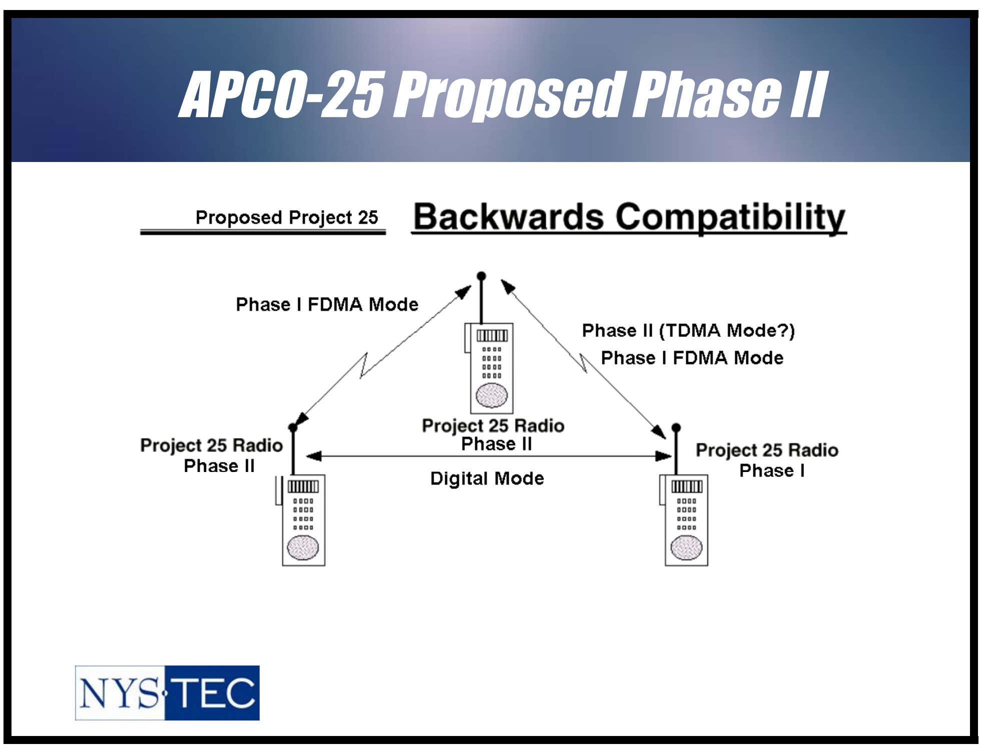

Figure 33, APCO-25, Proposed Phase II

Most of the Project-25 radio system interfaces are standardized, with the most important being the Common-Air-Interface (CAI). A common-air-interface enables radios from different vendors to communicate with each other. Project 25 Phase II standards are currently under development, and mandate twice the spectral efficiency of Phase I. Project 25 requires a well-planned migration strategy from Phase I to Phase II — both in the forward and backward direction. While Project-25 has developed the CAI standard to accommodate the more spectrally efficient Phase II operation, only Phase I equipment has been manufactured so far.

4.2.3 Key Standard Interfaces

The major thrust to create Project 25 was open standardization on all key interfaces with components in the system. These standard interfaces guarantee interoperability of different vendors' equipment. The impact for users is that any subscriber component (portable, mobile, or MDT) from any vender will work on any system. A user must first be a valid user on his, her, or a visiting system; however, interoperability is always an option to a Project 25 user. The other significant impact of the standardization is that system managers can enjoy competitive procurements for the system throughout its service life.

Project 25 specifies the following interfaces:

- Air Interface - The air interface between the mobile and base station, and a direct-mode air interface between two mobile units defines how data is sent over the air. Also known as CAI (Common Air Interface) because this digital air interface is accessible through different vendor's subscriber equipment.
- Terminal Equipment Interface - This interface is between a mobile unit and its data terminal. This permits development of data applications that will work with each other.
- Inter-System Interface (ISI) - The ISI is a defined connection between two Project 25 networks, allowing the interconnection of Project 25 networks from different manufacturers.
- Gateways - These provide access from the Project 25 network to other networks like the PSTN (Public Switched Telephone Network), ISDN (Integrated Services Digital Network), or PBX (Public Branch Exchange). These gateways provide access for basic voice and data communication and provide an address-translation operation between Project 25 identities and other network-access numbers.
- Network Management - The Network Management Interface provides a standard to remotely monitor and control network equipment.
- Line Station Interface - This interface permits the connection of third-party dispatch systems.

4.2.4 Systems in Operation

Project 25 has a strong deployed base within the United States. Many Project 25 municipal systems either exist or are in the planning stages; among them are the cities of Memphis, Mesa/Phoenix, Los Angeles, Baltimore, and Philadelphia. Several statewide systems also use

Project 25, with very large systems in Michigan[31] and Ohio and several smaller scope projects in progress in the States of Indiana, Minnesota, Kentucky, and Connecticut. Project 25 also has tremendous support at the federal level, with many agencies utilizing Project 25 technologies for their system upgrades. Federal agencies have been closely involved in the Project 25 standards-development process.

Motorola is the largest radio and system provider of Project 25 compliant equipment, and is the vendor that has dedicated the most technical and financial resources into the development of Project 25 standards and equipment.

4.2.5 Viability of P 25 Technology for Tompkins County

Now that background on the possibility for Project 25 technology has been presented for the Tompkins County system, the material that follows gives the important considerations that will help determine its viability for the County.

Important considerations with P 25 Technology.

- ***Availability outside the U.S. - Availability within the U.S.***

Intended as a truly open standard, Project 25 has no limitations on global usage. In fact, while predominantly a U.S.-deployed technology, Project 25 systems are starting to be procured worldwide.

- ***Maturity of Technology***

With a large number of systems deployed, Project 25 Phase I is as mature as one can expect of a fairly new technology. No significant implementation issues are known of at this time. The core suites of standards have been in place since 1995. However, the more spectrally efficient Phase II technology standards are still under development.

- ***U.S. 800-MHz Compatible***

Project 25-based equipment is currently available in the 800-MHz band.

- ***U.S. 700-MHz Compatible***

Project 25-based equipment will be produced in the 700-MHz band. In fact, the Project 25 CAI is anticipated to be the standard interface chosen by the FCC for operation on the 700-MHz interoperability channel set.

- ***Integrated Voice and Data***

Project 25 offers the capability of voice and data integrated into the same radio — but cannot offer these simultaneously over the same radio channel. In addition to this, due to technical limitations of current FDMA voice and data protocols, most deployments utilize a separate data system overlay with dual subscriber radio units in each vehicle. This tends to increase overall system and equipment costs.

- ***Bandwidth on Demand***[32]

Project 25 does not offer this functionality.

[31] The NYSTEC/SWN project team had visited the primary and back-up network control centers of the Michigan system in September of 1999, at the leading edge of their transition P-25 digital technology.
[32] This feature automatically increases data transfer rates if system traffic permits. This allows users to obtain their files transfers more quickly, without affecting or delaying system access, and allows for extremely efficient voice and data integration.

- ***Spectral Efficiency***

Currently available (Phase I) Project 25 technology offers two voice paths within a 25-kHz channel. Future technologies (Phase II) will offer four voice paths within a single 25 kHz channel. However, Phase II equipment availability is still several years off.

- ***Simulcast Operation***[33]

The currently available (Phase I) Project 25 technology offers this functionality — which is important to Tompkins County. It is expected that it will be extremely difficult for Project 25 Phase II technologies to offer this functionality.

- ***Overall Coverage***

In relative terms, the coverage of Phase I Project 25 technology is "good." This is mainly due to the fact that the Phase I digital modulation is not extremely complex — which is also the reason for its inferior spectral-efficiency performance. The coverage range of Phase II Project 25 technologies will be reduced, due to its use of a more complex digital modulation[34].

- ***Vehicle Repeater Coverage***[35]

Although there are Project 25 standards being drafted for this functionality, no standardized equipment is available at this time. Reports are that ANSI and the P 25 Steering Committees, in conjunction with their Working Groups, will finish this standard early in 2001. Manufacturers report equipment with some functional ANSI-102 vehicle repeater standards compliance will follow closely thereafter.

- ***Migration to Project 25 Phase II***

By virtue of the Project 25 standards process, Phase I and II equipment are expected to be both forward and backward compatible with one another.

- ***Siting Considerations on Tompkins County Transition***

Because the overall coverage of Phase I and Phase II technologies differ, it is expected that additional sites will be required to provide coverage of a Phase II technology from a Phase I infrastructure.

- ***Availability of Multiple Vendor Sources***

Although several vendors supply Project 25 equipment, the only vendor offering full-featured Project 25 systems and equipment is Motorola. E. F. Johnson will also offer Project 25 systems, but for small networks only.

- ***Subscriber Unit Cost***

Subscriber unit costs for a full-featured Project 25 radio are currently about $2400-4500. Mid-Tier portable and mobile units expected mid-2001 from Motorola and E.F. Johnson.

4.3 Terrestrial Trunked Radio (TETRA)

TETRA is the European digital trunked radio standards suite. The TETRA standards are defined by the European Telecommunications Standards Institute (ETSI), and are designed to meet the

[33] Simulcast operations allow for more effective spectrum usage over a geographic area.
[34] The use of a more advanced modulation technique affects the overall coverage in several ways. In general, it both lowers the power output of the equipment, and requires a higher level of signal to provide the same quality of service.

[35] This functionality allows a mobile radio to either extend the coverage of the system, or to provide a higher level of portable and in-building coverage at the scene of an incident. This functionality is extremely important to many Tompkins County agencies.

most demanding needs of both public-safety and commercial mobile radio users. Like Project 25, TETRA is the work of a consortium of corporations, agencies, and organizations that have signed a Memorandum of Understanding (MoU) with regards to the TETRA standards and technologies. However, unlike TIA, ETSI is a governmentally supported standards-development organization.

Because TETRA is a European-based technology, it was necessary for the NYSTEC/SWN project team to travel to Europe in 1998 in order to gain first-hand information about the performance and viability of TETRA technology. Since then, the SWN office and NYSTEC have encouraged TETRA vendors to forge a U.S. presence, and have held many subsequent meetings with them in the U.S. From these meetings, the NYSTEC/SWN project team has been able to better understand the issues, expectations, and concerns of the European vendors in regards to bringing TETRA to the U.S.

This section will explore TETRA's viability for the County as well as note TETRA's viability for the Statewide Wireless Network (SWN) project.

4.3.1 History

With support of the European Commission and ETSI members, the TETRA standard has been developed through the cooperation of manufacturers, Public Safety users, commercial service providers, and other experts, with an emphasis on ensuring that the standard will support the needs of emergency services throughout Europe and beyond. The concept of TETRA was initiated in 1990, and the first standards were completed in 1995 — within the same time frame as the core Project 25 standards. The TETRA MoU was established in December 1994 to create a forum that could act on behalf of all interested parties. Today the TETRA MoU represents 56 organizations from 19 countries. The manufacturing presence of this group represents practically the entire European mobile radio industry, and also includes major U.S. interests such as Motorola and Ericsson (now ComNet Ericsson).

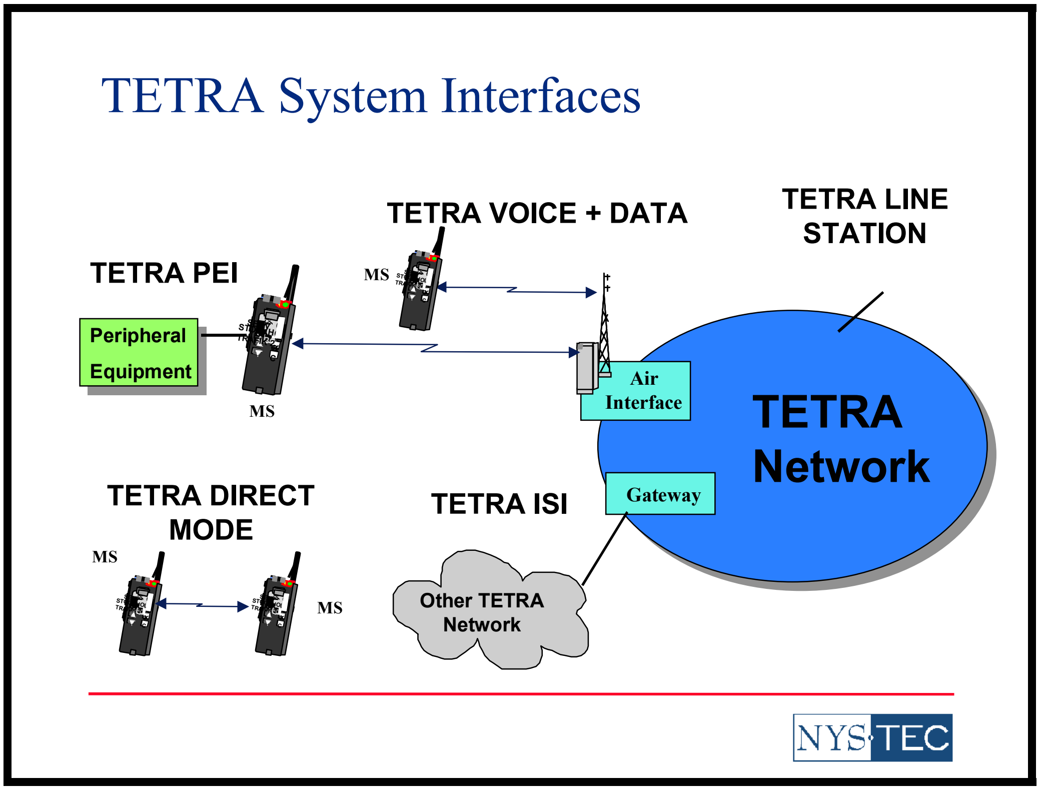

Figure 34, TETRA Standard System Interfaces

4.3.2 Technology

Like Project 25, TETRA is a standard that is continually evolving. However, its technology in many ways is more advanced than Project 25. TETRA utilizes Time Division Multiple Access (TDMA), which allows up to four voice or data communications to exist simultaneously within a single channel resource. This allows TETRA to offer twice the spectral efficiency of a Phase I Project 25 system. TETRA also offers additional advanced features, such adaptive bandwidth on demand, and coverage enhancement functionality that is a standard option for mobile radio equipment. While TETRA, like Project 25, is continually evolving, the core standards are mature and encompass most of the important radio system interfaces. TETRA, also like Project 25, includes a common air interface (CAI) that allows radios from different vendors to communicate seamlessly with each other.

4.3.3 Systems in Operation

According to industry observers, there will be 20 million TETRA subscribers worldwide by 2008, and there are already 50 contracts and commitments for TETRA projects worldwide, representing a combined value of more than $2.5B. TETRA systems can be found nearly everywhere in the world, as illustrated in Figure 35. The size and scope of many of these systems dwarfs the scope of currently envisioned Project 25 systems, with many national systems underway, including the United Kingdom (all Isles), Hungary, Romania, Croatia, Italy, Spain, and others. Many large municipal[36] projects are also underway including Beijing, Hong Kong, the London Underground, Athens Airport, and the St. Petersburg Metro. TETRA has also proved rugged, reliable, and advanced enough to serve in a military role. It is being considered by many defense agencies, and is currently being used by the Israeli Defense Forces.

From the beginning, TETRA was also designed with features that allow it to support professional commercial wireless services, and it has excelled in that role. It has become the primary technology of Dolphin Telecommunications Ltd., of the European group Dolphin Telecom. Dolphin is the largest public mobile radio network operator in Europe, with approximately 272,000 subscribers in the UK, France, Belgium, Germany, Spain, and Portugal.

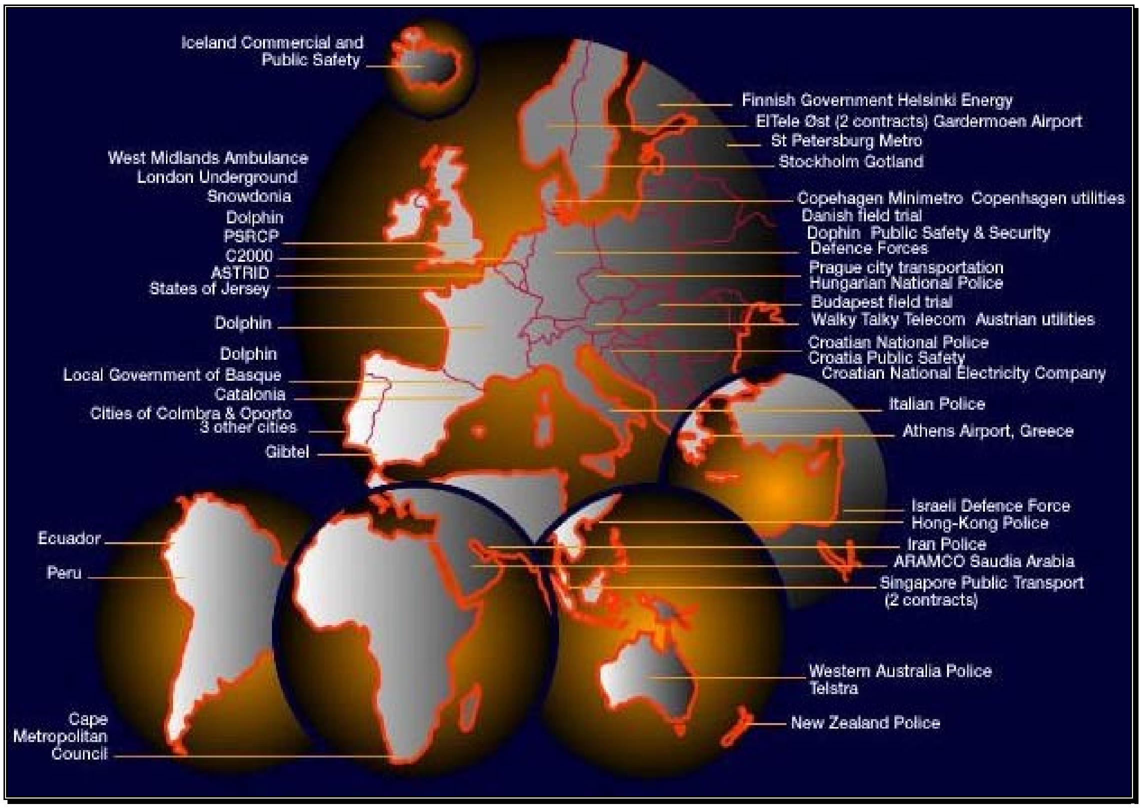

Figure 35, TETRA Systems Deployed throughout the World[37]

A close inspection of Figure 354 also reveals one critical feature of TETRA system deployments — there are no North American TETRA systems implemented or being planned in the near future.

TETRA development took advantage of intellectual property rights (IPRs) of multiple manufacturers. TETRA development was also greatly fostered by a European-wide reallocation of spectrum from 380 MHz to 400 MHz. The North Atlantic Treaty Organization (NATO) counties, whose military users were called upon, made the spectrum available so that the

[36] The NYSTEC/SWN team had been able to visit an operational Motorola TETRA system on the Isle of Jersey during the 1998 European TETRA fact-finding expedition.
[37] TETRA Memorandum of Understanding (MoU) web site, http://tetramou.com

European Union (EU) nations would have contiguous spectrum or a “harmonized” band throughout all the EU. Other nations have followed suit. TETRA has since been adapted for other frequency bands as well, most notable the 800-MHz band.

IPR use among manufacturers for the European market was facilitated under the ETSI cross-licensing agreement. Further, manufacturers have licensed their IPRs to one another and allow the sale of TETRA equipment in Asia, Australia, and the Pacific.

In North America, the situation appears to be different. Not all of the essential IPRs are granted for use in North America. Factors like non-disclosure agreements, company policies, and commercial contracts between TETRA manufacturers cloak IPR-licensing particulars. Most TETRA proponents name Motorola as the sole reluctant IPR hold-out in North America. However: “I would expect them to say that — to cast Motorola as the bad guy,” said Patricia Sturmon, Motorola’s senior manager of public relations. “If I were them, I would use the same tactic. The truth is, Motorola is not the only company that has to give an IPR license for TETRA to be sold in North America.”[38]

Undoubtedly there are a number of private commercial contracts between TETRA manufacturers that deal with markets and where the IPRs can be used; however Motorola does seem to be the holder of the lion’s share of these IPRs. Could it be that the reason for Motorola’s reluctance for domestic TETRA offering is that it is protecting its estimated 80% market share of the U.S. public-safety radio system sales. While it is true that Motorola is the largest TETRA supplier in the world, its percentage of TETRA market share is smaller than its percentage of U.S. market share — where TETRA is not currently available. Motorola has indicated that it would allow TETRA to enter the North American market if it became accredited as a U.S. standard (most likely a Project 25 Phase II standard). While it may not be fair to totally make Motorola the villain in this controversy, clearly TETRA is being kept out of the U.S. market for reasons that are not technical.

4.3.4 Viability of TETRA-Based Technology for Tompkins County

This section examines the technology in more detail to see how viable a solution it is for Tompkins County. This section examines the characteristics of TETRA as it relates to the Tompkins County LMR project, and also examines how it will affect the inevitable technology evolution that Tompkins County must undergo, as well as the realistic possibilities for use of this technology.

- ***Availability outside the U.S. - Availability within the U.S.***

Due to IPR issues, TETRA has not been available in the United States or Canada. This may be an insurmountable problem. Outside of these areas, TETRA is available worldwide. One avenue for bringing TETRA to the U.S. is through its acceptance as a Project 25 Phase II standard. Other avenues include litigation over IPRs or the waiver of North American IPR constraints.

[38] Mobile Radio Technology, Jan 1, 2001, *Coming to America: TETRA-One Way or Another.*

- ***Maturity of Technology***

With a large number of systems deployed, TETRA is as mature as one can expect from a fairly new technology. No significant implementation issues are known of at this time. The core suites of standards have been in place since 1995, with equipment available since several years later.

- ***U.S. 800-MHz Compatible***

TETRA-based equipment is currently available and is being deployed in the 800-MHz band. The use of TETRA within certain portions of the United States 800-MHz band would require FCC waivers.

- ***U.S. 700-MHz Compatible***

If TETRA does become available within the U.S., it is expected that 700-MHz equipment would be offered. It will likely require inclusion of the Project 25 CAI for operation on the 700-MHz interoperability channel set. This may require a dual-mode capability.

- ***Integrated Voice and Data***

TETRA offers seamless integration of voice and data as a standard feature of the technology. This will tend to lower overall system and equipment costs, due to less duplication of equipment.

- ***Bandwidth on Demand***

TETRA offers this functionality as a basic characteristic of its technology.

- ***Spectral Efficiency***

From its onset, TETRA has offered a spectral efficiency of four talk paths in a single 25-kHz channel. This is equal to the performance that Project 25 Phase II is targeting, but is not expected to offer for several years. This is also the spectral efficiency that the FCC will ultimately require for 700-MHz band operations.

- ***Simulcast Operation***

Currently available TETRA equipment and systems do not offer this functionality — which could be important to Tompkins County. However, simulcast operations are included within the TETRA standards, and work continues toward offering this functionality in the future. In addition to this, TETRA vendors have developed alternative solutions that serve the same purpose as simulcast.

- ***Overall Coverage***

Because of its spectral efficiency and complex modulation, TETRA's overall coverage is reduced when compared to that afforded by Project 25 Phase I technologies. However, it should be roughly equivalent to the coverage afforded by Project 25 Phase II technologies.

- ***Vehicle Repeater Coverage***

TETRA offers an extremely advanced version of this functionality as a basic subscriber equipment option.

- ***Migration to Project 25 Phase II***

TETRA can be modified to become a Project 25 Phase II technology. In fact, it is one of several technologies under consideration at this time. However, TETRA is not as easily modified as Project 25 Phase I is for this purpose.

- ***Siting Considerations on Tompkins County Communications System Transition***

Because there is much less of a difference between the coverage characteristics of TETRA and Project 25 Phase II, it is expected there will be much less of a siting impact from a transition of these technologies. As a consequence, if any additional sites are required, it will be much less than the number required for a Project 25 Phase I to Project 25 Phase II transition.

- ***Availability of Multiple Vendor Sources***

Multiple vendors exist for both full-featured equipment and full systems. In all, nineteen separate vendors supply either radios or infrastructure equipment. The largest of these are Nokia, Motorola, Simoco/Frequentis, and Marconi/ComNet Ericsson[39].

- ***Subscriber Unit Cost***

Subscriber unit costs for a full-featured European TETRA radio are currently about 1000-3000 in U.S. dollars. TETRA vendors have not yet predicted the costs of dual-mode "U.S. TETRA" units. It is expected that multiple-vendor availability of subscriber units will help keep costs as low as possible.

- ***Infrastructure Cost***

Because multiple vendors offer full-featured system and infrastructure equipment, it is expected that the competition level will keep market prices for TETRA infrastructure equipment relatively low. Given the market issues over IPRs, the County should not expect that TETRA is a realistic option for the near future.

[39] The NYSTEC/SWN project team has seen several demonstrations showing that radios from most of these vendors (Motorola was not a participant) are interoperable with each other on a TETRA system.

5. SATELLITE TECHNOLOGY

Satellite technology continues to be key for telecommunications and is growing in its use for wireless Internet connection. Because of the physics constraints and costs of its operations, it is a limited option for communities like the Tompkins County. Satellite providers offer benefits such as wide-area coverage in rural or remote areas where terrestrial service has not been built out or may never be extended, particularly for fixed location operations, such as at a command center. Its utility for users "on the move," such as public-safety field personnel, is limited because of:

- Call set-up times are long,
- Long delay times in transmissions severely hinder two-way voice communications,
- Direct line of sight to the satellites is required, thus there is no in-building coverage,
- Bulky mobile and portable user equipment is bulky, and
- The per-minute charges for service are expensive.

Satellites are generally characterized first by their orbit altitude. Each altitude has different advantages and disadvantages. These orbit-altitude differences are generally classified as low earth orbit (LEO), medium earth orbit (MEO), and geostationary earth orbit (GEO), ash shown in Figure 36. Table 8 shows the different orbits used by different satellites constellations. It also can serve as a quick reference of the characteristics of the three main orbit types.

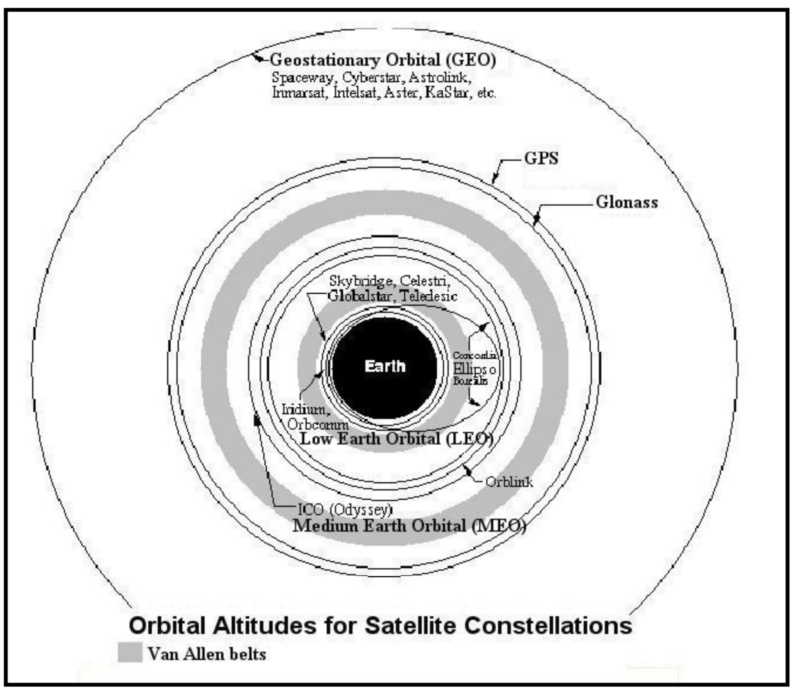

Figure 36, Satellite Orbital Altitudes

Table 8, Types of Satellite Orbits and Configurations

Satellite Orbit: LEO vs. MEO vs. GEO (cont.)

Orbit	LEO	MEO	GEO
Orbit Altitude (km)	480 to 1600	8050 to 16,100	35,787
Constellation	Uses a multiple (10's to 100's) satellite constellation to provide full earth coverage	Fewer satellites (10-20) than LEO are necessary to provide full earth coverage	Provides continuous coverage to one area of earth
Orbital Dynamics	Each satellite moves rapidly across the sky; satellite-to-satellite handoffs	Satellites move slowly across the sky; fewer handoffs than LEO	Stays in one position in sky (24 hour orbit matches Earth's rotation)
Round Trip Delay	Small: 20 to 40 ms	Moderate: 50 to 150 ms	Large: 250 ms
Example Systems	Iridium (now bankrupt), Globalstar, Orbcomm and Teledesic	ICO	GE American, Galaxy, PanAmSat and INTELSAT

5.1 Satellite Dynamics

LEO (Low Earth Orbit) Satellites: LEOs have either elliptical or, more commonly, circular orbits at a height of less than 2,000 km above the surface of the earth. The orbit period at these altitudes varies between ninety minutes and two hours. The orbital altitude ranges from about 480 to 1600 km or 300 to 1000 miles above the earth. The time during which a satellite in LEO orbit is above the local horizon for an observer on the earth is up to 20 minutes. A global communications system using this type of orbit requires a large number of satellites in a number of different, inclined, orbits. When a satellite serving a particular user moves below the local horizon, it needs to be able to hand off the service to a succeeding satellite in the same or an adjacent orbit. Due to the relatively large movement of a satellite in LEO with respect to an observer on the earth, satellite systems using this type of orbit need to be able to cope with large Doppler shifts. Satellites in LEO are also affected by atmospheric drag, which causes the orbit to gradually deteriorate.

LEOs are constellations that offer portable subscriber equipment because they are close enough to the earth that the link forward and back is achievable. The round trip delay is small, about 30 ms, and the system is therefore usable to public safety for voice needs, but the call set-up time ranges from 10 to 30 seconds, which is unacceptable for public safety. In addition the services currently available only provide point-to-point real-time voice communications. The problem that LEO constellations face is that, because of the 90-minute period, they need large numbers of satellites in multiple orbital slots to cover an area like the U.S. all the time.

MEO (Medium Earth Orbit) Satellites: MEOs are usually circular orbits at an altitude of around 10,000 km (6250 miles) above the earth. Their orbit period ranges from 6 to 12 hours.

The maximum time during which a satellite in a MEO orbit is above the local horizon for an observer on the earth is on the order of a few hours. A global communications system using this type of orbit requires a modest number of satellites (~10) in 2 to 3 orbital planes to achieve global coverage. MEO systems are operated in a manner similar to LEO systems; however, compared to a LEO system, hand-off is less frequent, and propagation delay and free space loss are greater.

Like LEOs, MEOs are constellations that offer portable subscriber equipment because they are close enough to the earth that the link forward and back is still usually achievable. The round trip delay is still relatively small, about 100 ms, and is therefore usable to public safety for voice needs. However, the call set-up time ranges from 10 to 30 seconds, which is unacceptable for public safety. The problem that MEO constellations face is that the 8-hour period still requires numerous satellites in multiple orbital slots to cover an area like the U.S. all the time.

GEO (Geostationary) Satellites: A geostationary orbit is a circular orbit in the equatorial plane with an orbital period equal to that of the Earth, which is achieved with an orbital height of 35,700 km (22,300 miles) above the earth. A satellite in a geostationary orbit will appear fixed above a point on the surface of the Earth's equator. In this condition, the satellite's period about the earth is the same as one day, thus it stays over the same point on the surface as it moves through its orbit.

In practice, the orbit has small, non-zero values for inclination and eccentricity, causing the satellite to trace out a small figure eight in the sky. The footprint, or service area, of a geostationary satellite covers almost 1/3 of the Earth's surface (from about 75 degrees South to about 75 degrees North latitude), so that near-global coverage can be achieved with a minimum of three satellites in orbit. A disadvantage of a geostationary satellite in a communication system is the round-trip delay of approximately 250 milliseconds.

Unlike LEOs, GEOs do not offer portable subscriber equipment because they are not close enough to the earth for the link forward and back to be achievable in a hand-held unit. Therefore GEO systems are usually built into mobile units or installed as fixed sites. The round-trip delay is still relatively large, about 250 ms, and is therefore not usable to public safety for voice needs. With such a delay, any two-way conversation would have at least ½-second total delay in it. The advantage that GEOs have is that one satellite can cover an area as big as the U.S. and, because of the 24-hour period, one satellite staying "in place" will be all that is required — thus eliminating the need for multiple satellites.

5.2 General Overview of Satellite Systems

This section gives an overview of a wide range of satellite systems that are currently in use.

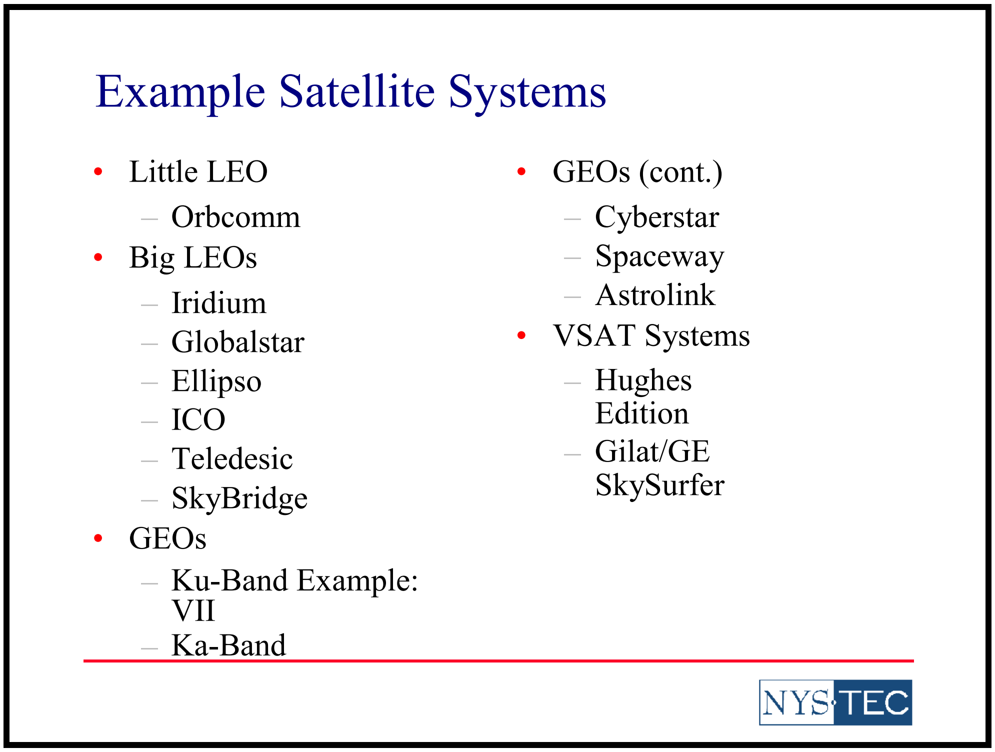

Figure 37, Overview of Satellite Systems

5.2.1 Example of a Little LEO, Orbcomm

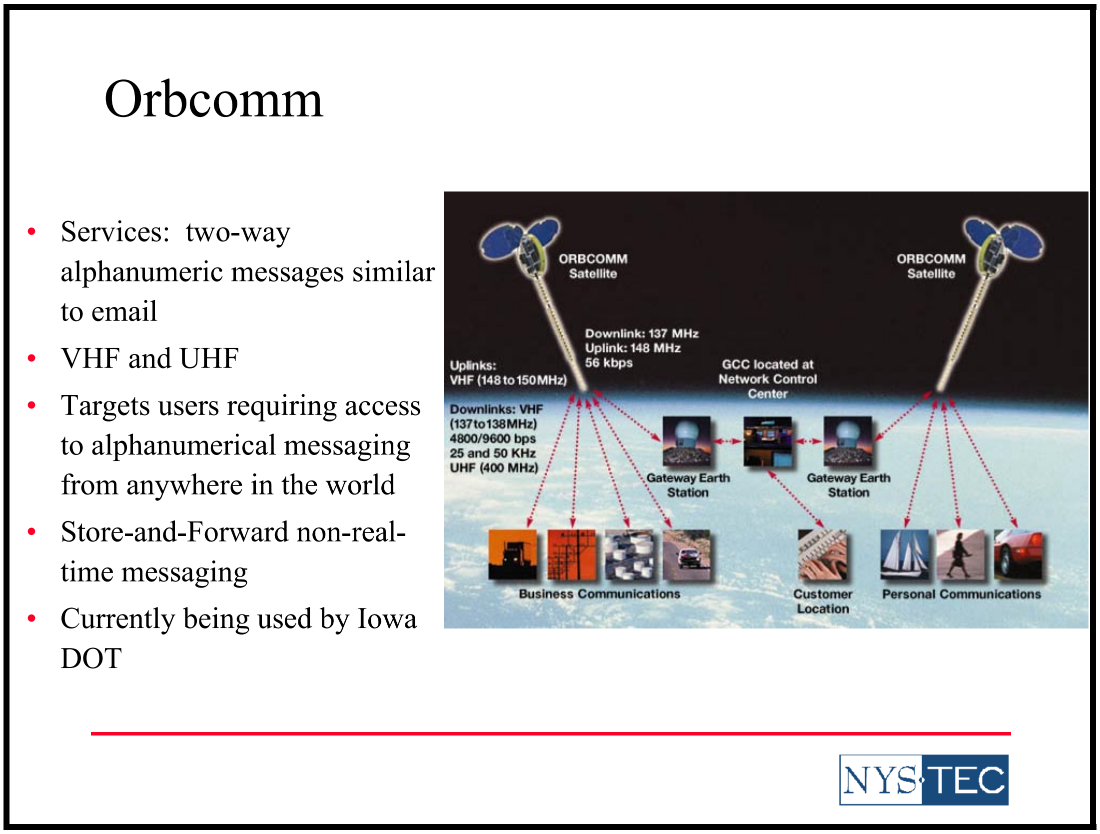

Figure 38, Orbcomm System

The Orbcomm System uses LEO satellites instead of terrestrial fixed-site relay repeaters to provide worldwide store-and-forward messaging. Costs are $15-$30/month; $0.007/byte for usage for basic monthly service. User equipment cost about $600 ($150-$200 in quantity). The system is capable of sending and receiving two-way alphanumeric packets, similar to two-way paging or e-mail. The main components of the Orbcomm system are:

- Gateways, which include the Gateway Control Centers (GCCs) and Gateway Earth Stations GESs),
- Network Control Center (NCC) located in the United States, and
- Subscriber communicators (SCs) — hand-held devices for personal messaging, as well as fixed and mobile units for remote monitoring and tracking applications.

Since November 30, 1998, Orbcomm has been in full commercial service. The message-delivery reliability exceeds 99.99%, and end-to-end latency averages less than 20 seconds from satellite contact. Orbcomm satellite system capacity is approximately 1 million messages per hour, or nearly 10 billion per year, on a global basis.

5.2.2 Examples of Big LEOs; Iridium, Globalstar, Ellipso, ICO, Teledesic, and SkyBridge.

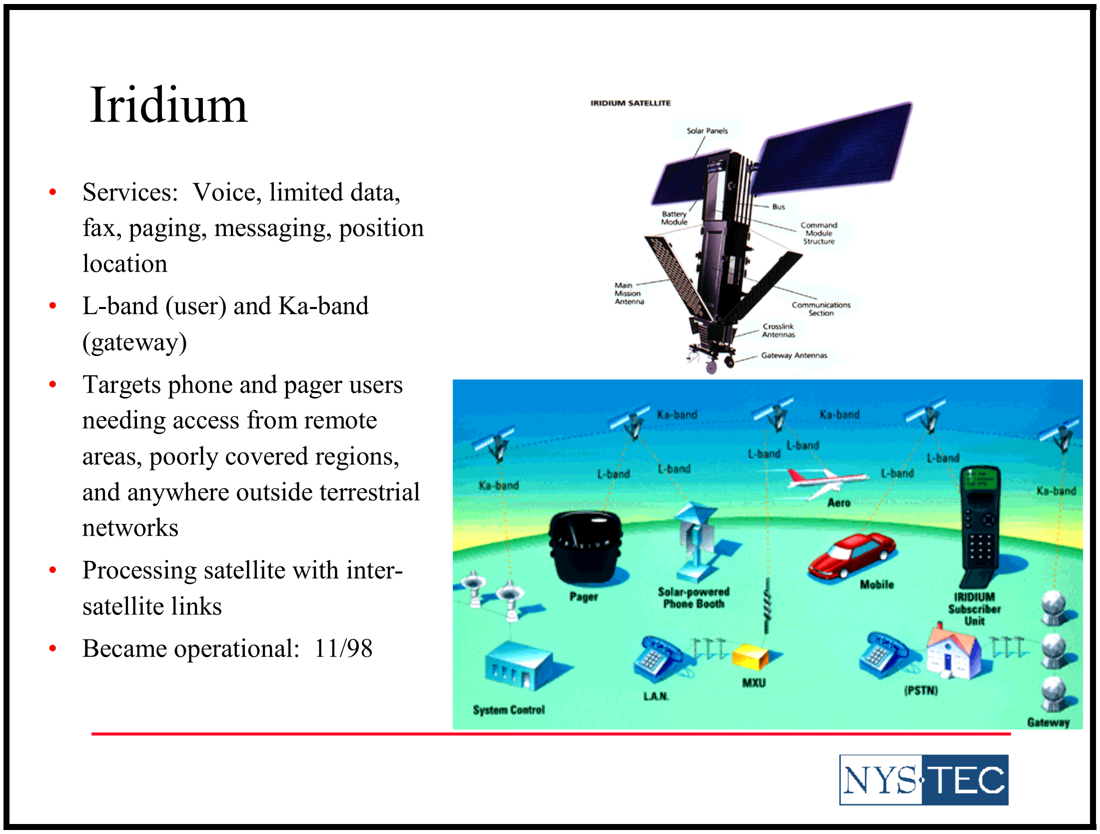

Figure 39, Iridium System (No Longer in Service)

With 66 satellites forming a cross-linked grid above the Earth, the Iridium system was the first LEO system for wireless telephone service. Iridium was essentially a cellular phone system in reverse — towers and cells move while users are effectively stationary. Only 780 km (485 miles) high, these satellites work differently from those at a much higher orbit (36,000 km) in two major ways. First, they are close enough to receive the signals of a hand-held device; and, second, they act like cellular towers in the sky — where wireless signals can move overhead instead of through ground-based cells.

Iridium did provide point-to-point telephony and paging coverage virtually anywhere in the world: Iridium World Satellite Service provided a direct satellite link for both incoming and outgoing communications in remote areas, poorly covered regions, and locations outside terrestrial networks.

The Iridium phone sold for about $2700. Service was $50.00/month, with $2.00-$8.00 per minute of air-time charges. It was operational from November 1998 to May 2000. Its multi-mode capability allowed the telephone to work as a typical cellular telephone (in areas where compatible cellular service exists) and as a satellite telephone with a data rate of 4.8 kbps. Additionally, it allowed the user to keep one telephone number and receive one telephone bill for calls made anywhere on earth. In addition to the $50 per month charge, users paid an average of $3 per minute.

Currently slated for destruction, this constellation is no longer in service.

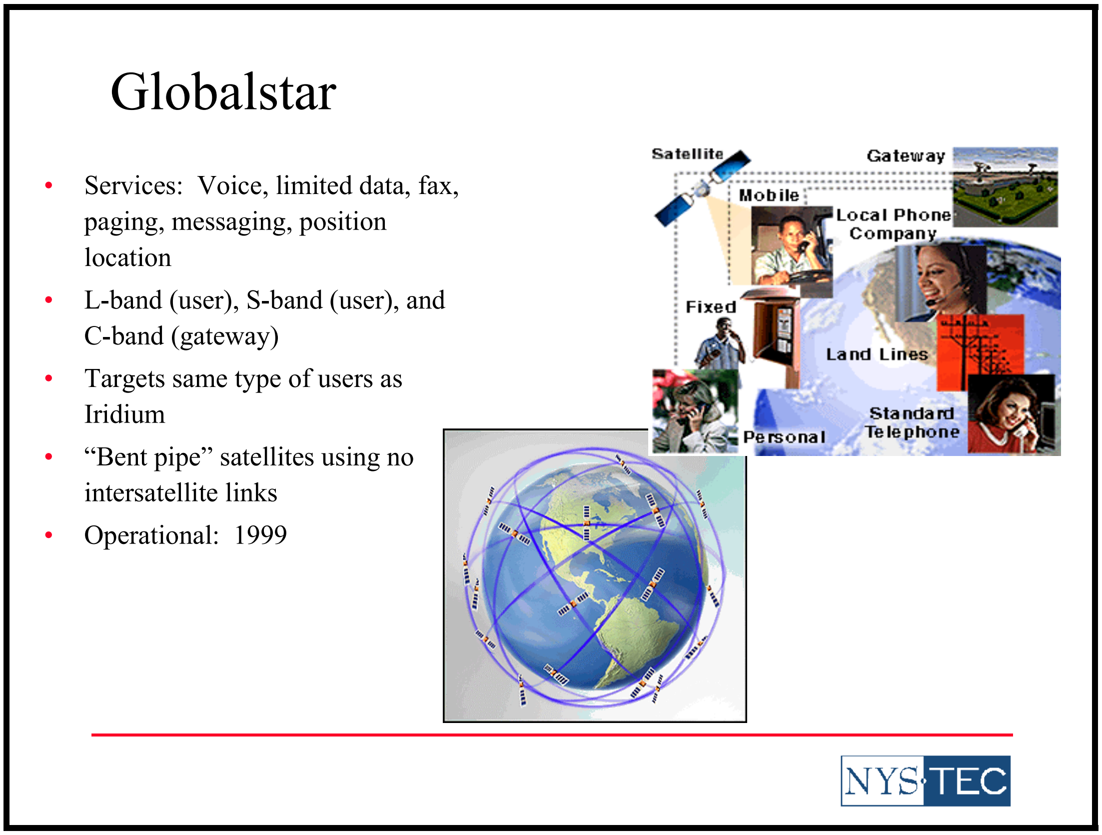

Figure 40, Globalstar System

The Globalstar system has 48 LEO satellites in eight planes. The constellation is designed for 100% single-satellite coverage between ±70° latitude, and 100% two-satellite (or better) coverage between 25° to 50° latitudes. Costs are expected to be $1.50-$2.99 per minute; $1,500 per user handset. Globalstar will employ path diversity combining to mitigate blocking and shadowing; as many as three satellites may at any one time be used to complete the call.

Globalstar uses Code Division Multiple Access (CDMA) technology. Globalstar offers data rates at 1200, 2400, 4800, and 9600 bps, and the vocoder rate is allowed to drop down to 1,200 kbps when no voice activity is detected. This reduces interference and increases capacity, while maintaining synchronization and conveying background comfort noise. Globalstar's antennas are shaped for elliptical beams aligned with the satellite's velocity vector to increase the time a user stays within each beam. Globalstar's bent-pipe satellites are much simpler than Iridium's processed satellites.

The Globalstar system provides interconnection to the PSTN/PLMN (Public Switched Telephone Network/Public Land-Mobile Network) through 100 to 210 earth stations. Globalstar will sell access to the Globalstar system to local service providers, which will have an exclusive regional right to offer the Globalstar service, as well as an obligation to obtain necessary regulatory approval. As with Iridium, calls will only be established through satellite(s) when connections cannot be made over the terrestrial network. All calls that are connected through the Globalstar system will be connected through the regional earth stations, giving the local service provider additional revenue and enabling local regulatory authorities to maintain control.

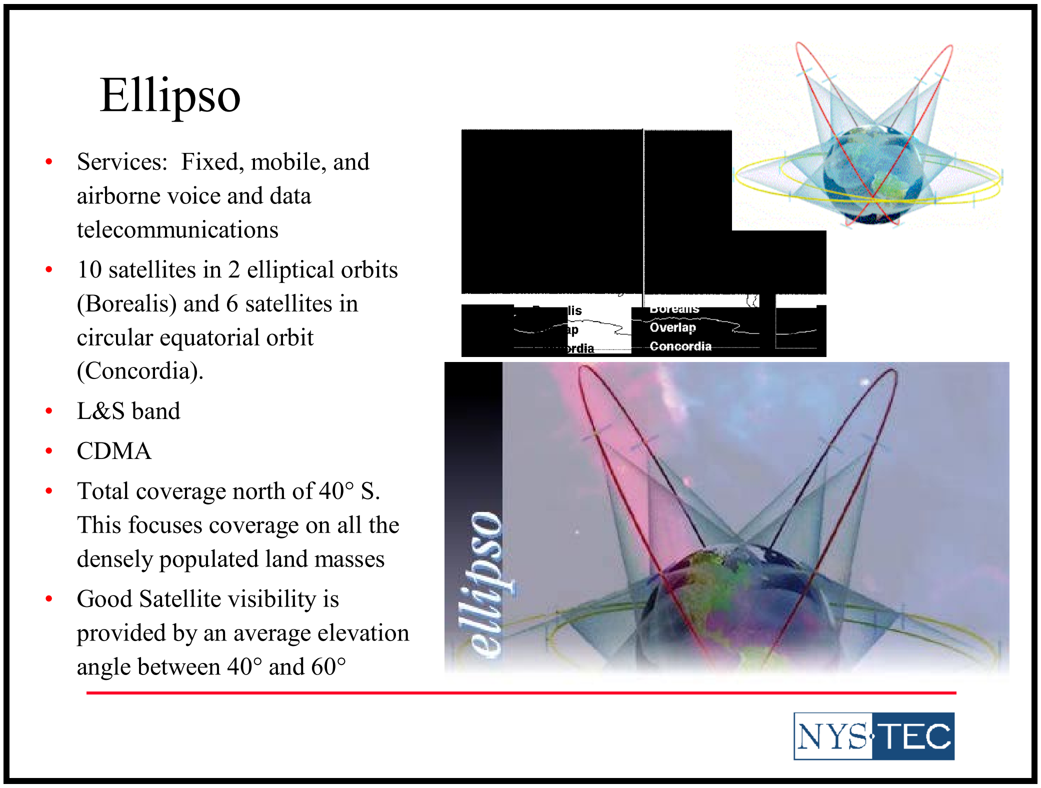

Figure 41, Ellipso System

Ellipso (service planned for 2002) is a global telecommunications system designed to extend and complement existing telephone and data networks. It offers voice and data communications services for about $0.50 a minute. In addition to telephony, Ellipso also offers other digital services: data transfer, facsimile, paging, voice mail, messaging, and geopositioning. As with Iridium and Globalstar, Ellipso will use terrestrial connections where possible. Ellipso will use simple bent-pipe transponder satellites similar to those of Globalstar.

The Ellipso constellation has a patented elliptical orbit configuration using two complementary sub-constellations totaling 17 satellites, including one on-orbit spare. In addition, one on-ground spare satellite will be built. The earth's distribution of land and population by latitude serves as the basis for the overall Ellipso constellation design.

Almost all the earth's populated land mass lies north of 40° S. In light of this asymmetry in populated landmasses, the Ellipso system was designed with inclined orbits to concentrate coverage in northern latitudes. If inclined circular orbits were used, equal coverage would be given to the far southern latitudes, where it is largely wasted. By making these inclined orbits elliptical (Ellipso-Borealis sub-constellation), these satellites will spend more time over the northern latitudes. The central and southern areas will be served by the circular subconstellation (Ellipso-Concordia). These two constellations are designed to offer high-minimum-elevation angles, which reduces the chances of blockage between users and satellites.

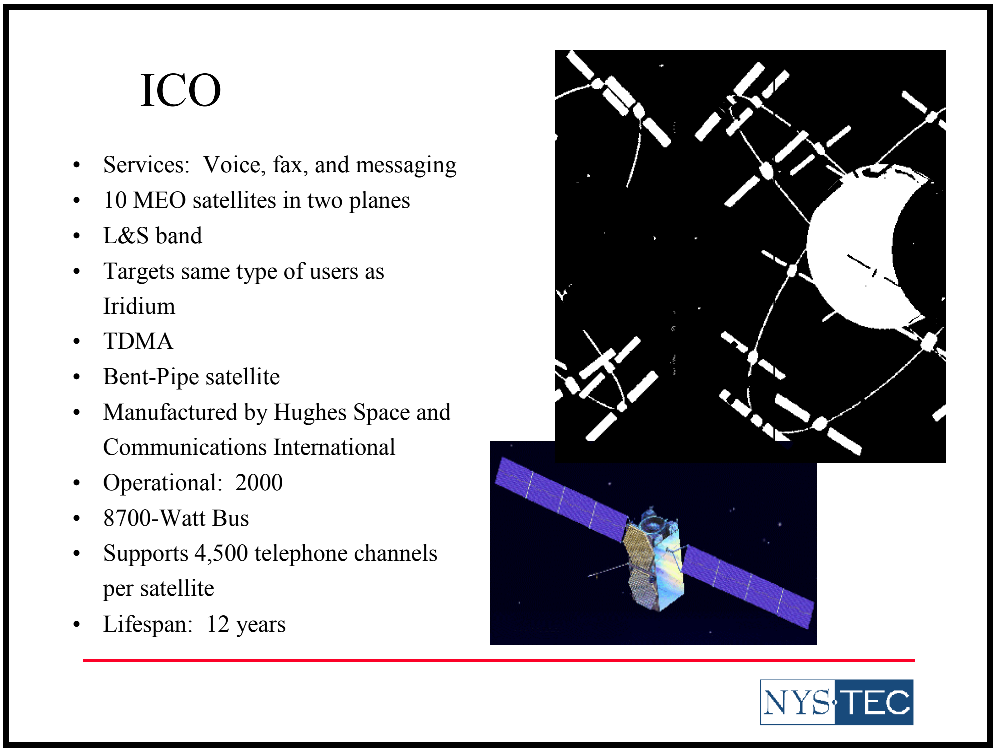

Figure 42, ICO System

ICO will provide service to hand-held mobile telephones, which, in outdoor environments, will offer services similar to those provided by normal cellular phones. In addition to voice, the ICO hand-held phone is planned to have optional features, including external data ports and internal buffer memory to support data communication, messaging functions, fax, and the use of smartcards (SIMs). The price of ICO dual-mode phones is expected to be competitive with those other comparable satellite systems. The costs are expected to be $1.00-$2.00/minute; $1000 in handset costs; and the service is scheduled to begin April 2001.

The system will route calls from terrestrial networks through the ICONET — comprising 12 Earth stations or satellite access nodes (SANs) located around the world and linked by high-speed cable.

A constellation of 10 satellites in medium Earth orbit (MEO) 10,390 km above the Earth's surface will be arranged in two planes of five satellites each. There will be one spare satellite in each plane. Hughes Space and Communications International is currently building the satellites under a contract signed in July 1995. Launches are scheduled to begin late in the first half of 1999. The satellites are based on the proven HS601 geostationary satellite bus and will have separate service-link (satellite-to-user) transmit and receive antennas.

The orbital pattern of the ICO constellation is designed so that as many as four satellites (usually two) will be in view of a user and a SAN at any time. The orbits have been selected to provide high elevation angles — average 40-50 degrees — to users.

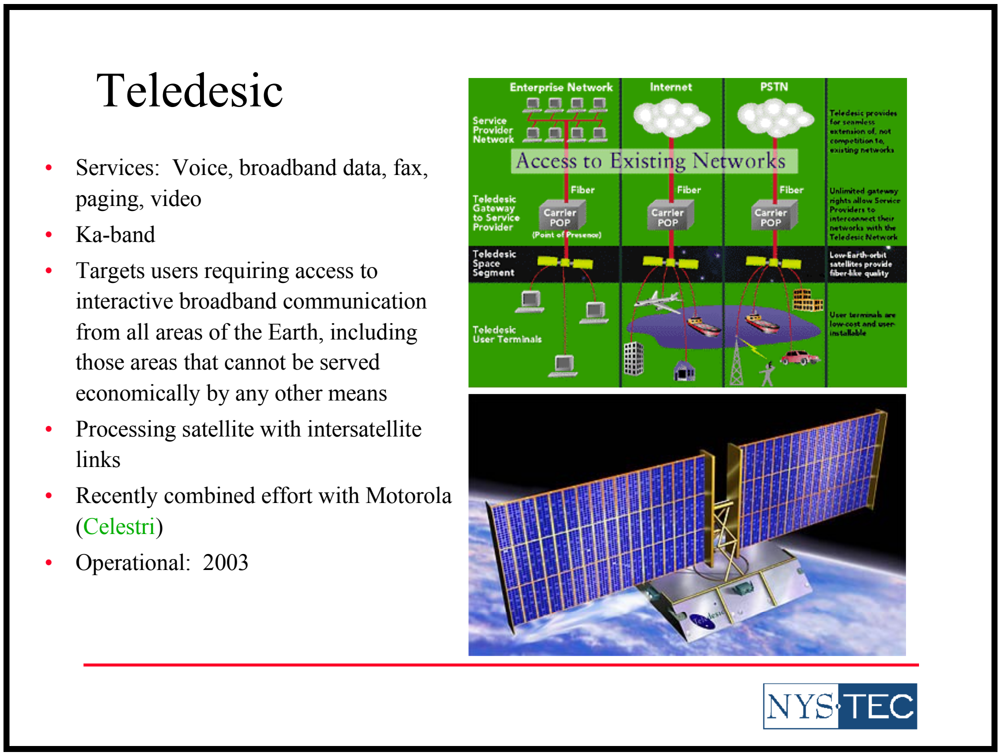

Figure 43, Teledesic System

Teledesic is building a global, broadband "Internet-in-the-Sky." Using a constellation of LEO satellites, Teledesic and its partners will create the world's first network to provide worldwide, "fiber-like" access to telecommunications services such as broadband Internet access, video conferencing, high-quality voice, and other digital data needs.

The Teledesic system is designed to support millions of simultaneous worldwide users. Teledesic will offer a family of user equipment to access the network. Most users will have two-way connections that provide up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. Higher-speed terminals will offer 64 Mbps or greater two-way capacity.

The Teledesic system's low orbit eliminates the long signal delay normally experienced in satellite communications and enables the use of small, low-power terminals and antennas. The laptop-size terminals will mount flat on a rooftop and connect inside to a computer network or PC.

Since combining with Motorola's Celestri, the exact status and configuration of the Teledesic constellation has been in question. Teledesic's most recent design was very ambitious, featuring 288 satellites. Celestri's more-conservative 63-satellite constellation is more realistic.

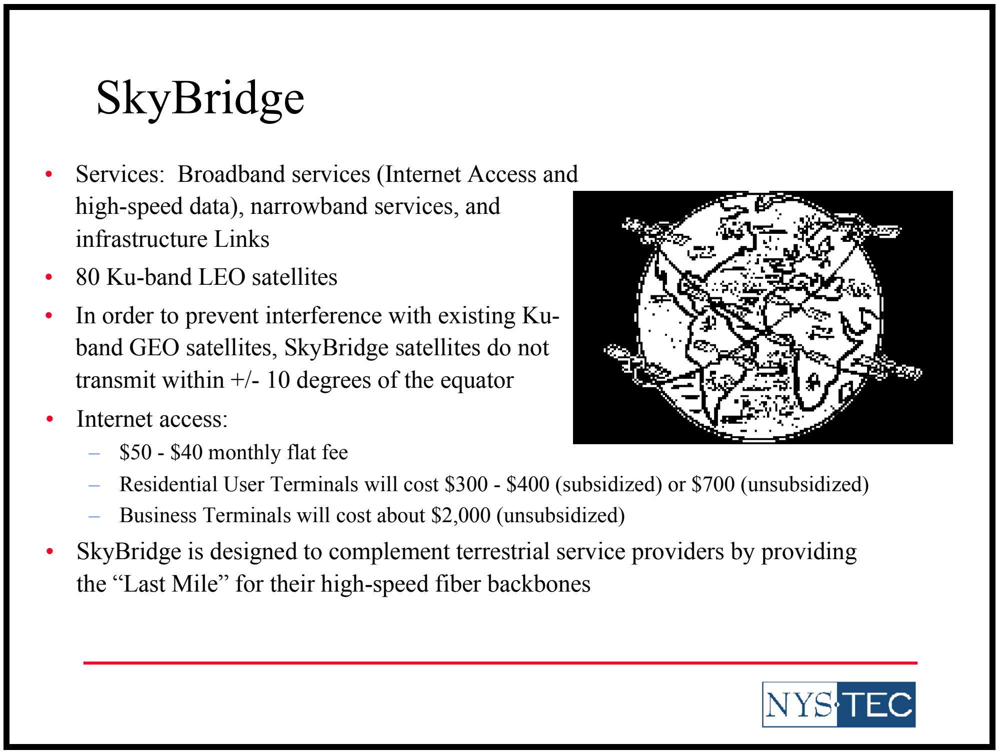

Figure 44, SkyBridge System

SkyBridge is a satellite-based system designed to provide global access to interactive, multimedia communications. Built around a constellation of 80 LEO satellites, SkyBridge provides the communications infrastructure for a full range of broadband services, including Internet access and high-speed data communications. Launch is scheduled for early 2002.

SkyBridge was designed to complement and extend terrestrial networks and help solve the “last mile” problem by providing an instant broadband connection to users that previously only had narrowband access. The SkyBridge system will optimize the use of the radio-frequency spectrum by operating in the Ku-band, while fully protecting geostationary satellite systems and terrestrial services within the Ku-band through an innovative frequency re-use concept: a SkyBridge satellite will not transmit when it is within 10 degrees of the geostationary arc.

The gateway handles interconnections with local servers and with terrestrial telecommunications networks; there is no need for direct links between satellites. Each gateway controls and manages all SkyBridge traffic within its respective coverage area. The gateways make it easy to offer customized services and local content adapted to local market requirements and preferences. SkyBridge services will be delivered locally through national and regional telecommunications operators and other service providers. The strength of SkyBridge lies in its relative simplicity using Ku-band technology with transponded satellites.

To provide narrowband service, a SkyBridge site is need in the same fashion (i.e., number of sites) as any LMR system would require by band. If this system were to be used as an LMR infrastructure, the same number of sites would have to be built in the county to support the subscribers; therefore, all this system would do is act as the switching network for all the calls.

SkyBridge would yield a poor and expensive switching network. It would be too slow and cause a great deal of call blocking (calls failing to get through). Further still, the cost to the County would also be far greater than desired, even when compared to an advanced digital microwave system.

5.2.3 Examples of GEOs, Ku-band and Ka-band types.

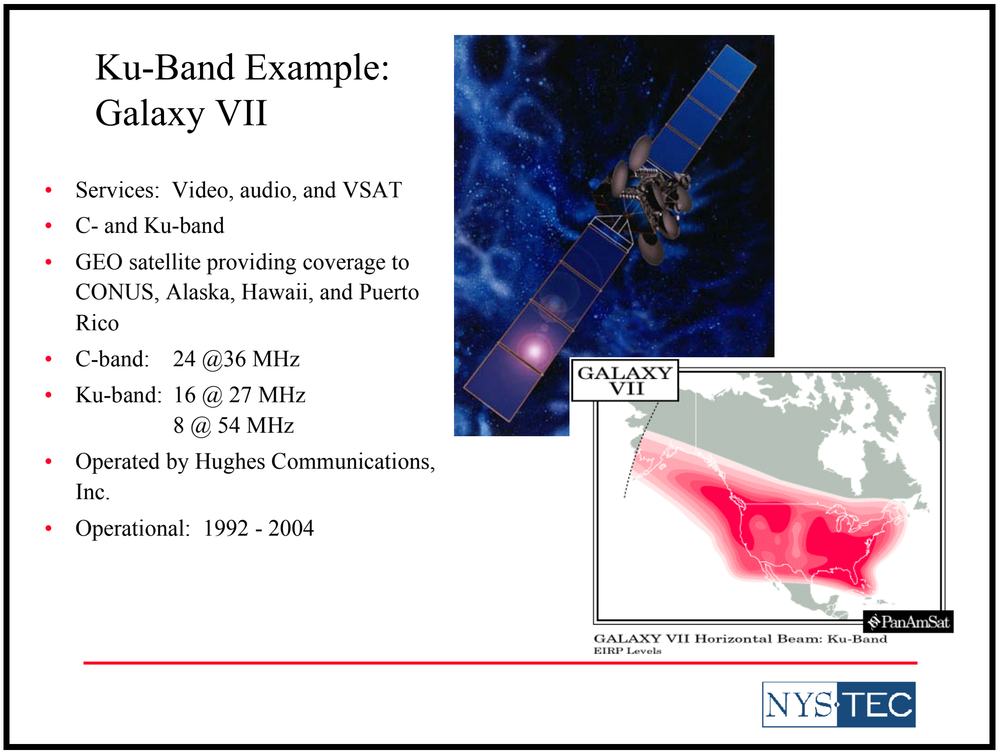

Figure 45, Ku-band Satellites

Ku-band satellites use, for the most part, "bent-pipe" technology: they receive whatever is sent up to them on one frequency and retransmit it back down on another frequency — there is no direct satellite-to-satellite communication. This architecture is excellent for point-to-multipoint broadcast services; e.g. DirectTV or remote training where many remote sites are spread out across a large geographical area. The Ku-band is used extensively for VSAT systems.

Services are usually procured with long-term leasing of transponders. This has the benefit of fixing the price for the user, but does not allow the user the flexibility of increasing or decreasing bandwidth as the user's needs change.

As with the Galaxy VII satellite described in Figure 45, many modern Ku-band satellites are actually dual-band satellites that also carry C-band transponders. Some of the more common Ku-band satellites are Galaxy, SpaceNet (used by SUNYSAT), Echostar, Intelsat, Orion, Telecom, and Telstar.

This system offers nothing to mobile users and has no options in a public-safety land-mobile system.

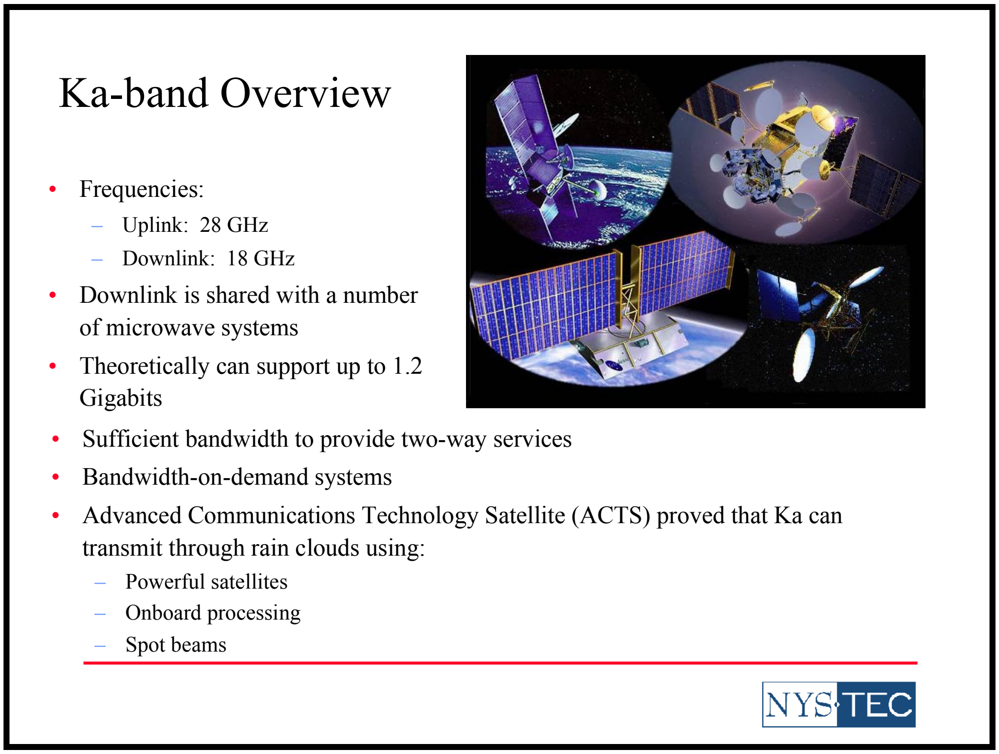

Figure 46, Ka-band Satellites

Until recently, the Ka-band has been a lightly used frequency band. Atmospheric loss was thought to be too much to overcome until ACTS and other experimental satellites proved that a powerful satellite with onboard processing and spot-beam technology could overcome atmospheric loss. This has opened up this frequency band for use in upcoming satellite systems. It is at a higher frequency, which allows user terminals to be much smaller than Ku-band terminals.

Today, Ka-band terminal equipment is expensive, but investments by military labs and, more recently commercial manufacturers are lowering equipment costs. Further cost savings will be realized when systems become operational and the number of units produced increases. The following three figures describe proposed Ka-band satellite systems.

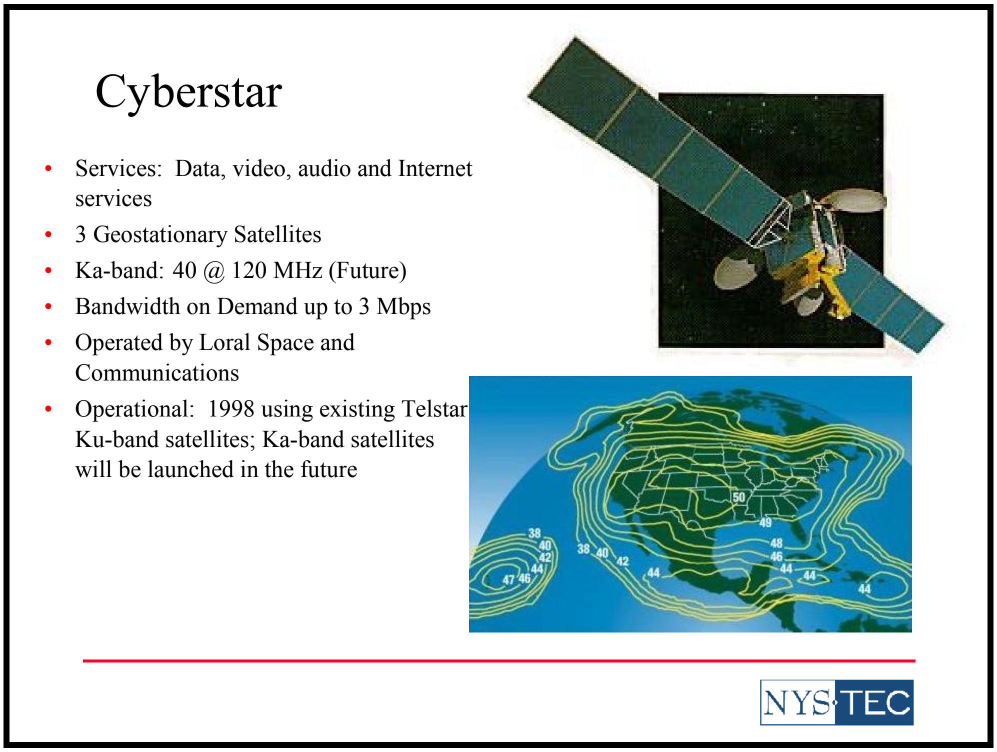

Figure 47, Cyberstar System

In October 1998, broadband satellite service provider CyberStar L.P. (Mountain View CA) launched its Cyberstar Ku-band service to corporate customers. The company, a division of satellite manufacturer Loral Space & Communications Ltd. (New York) says CyberStar's service will offer packages based on a basic connection with hardware components. For a startup cost of about $1,100, customers will receive a PC card, antenna installation, and a software package that enables their Windows NT servers and Windows programs to run CyberStar's service. Customers then pay a usage charge according to the number of sites hooked up to the service and the amount of data transferred. CyberStar can offer speeds of up to 29 Mbps as well as secure Internet protocol (IP) multicast sessions and high-speed file transfers. CyberStar can also be used for Media Streaming High-Speed Internet Access, Distance Learning, and Database Updates/Replication.

This system offers little to mobile users and has few options in a public-safety land-mobile system. Mobile data provisioning has been proposed, currently the products available (mounted in PCMCIA cards) are not proper products to press into public-safety land-mobile use without much special product development that would undoubtedly be very expensive.

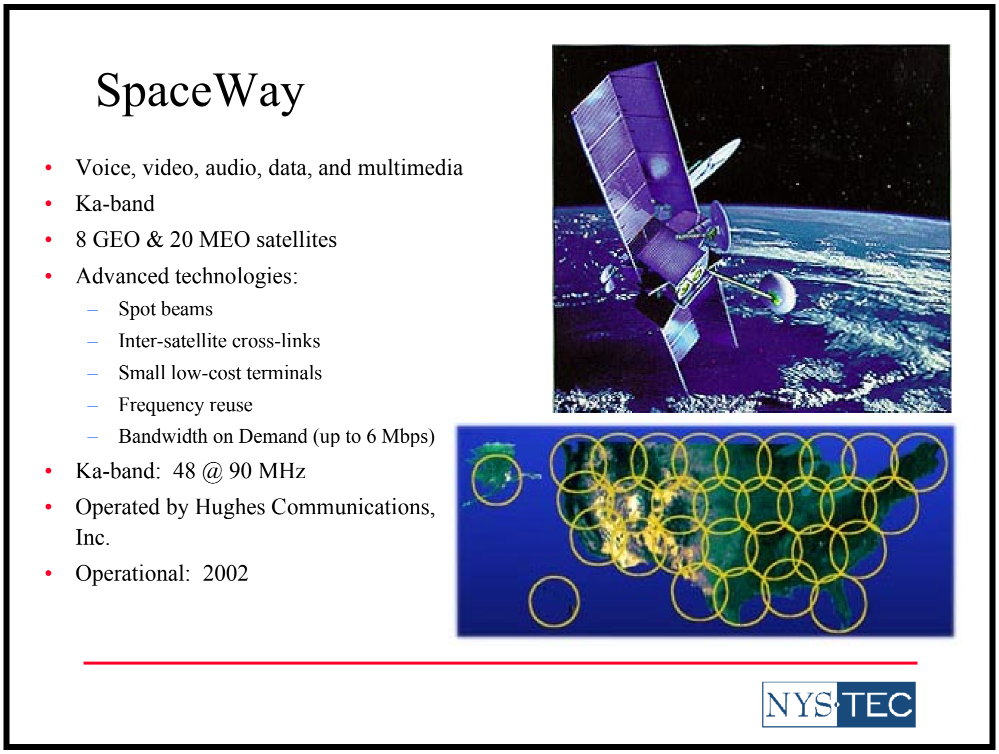

Figure 48, SpaceWay System

The SPACEWAY EXP™ will be an eight-satellite system operating in 4 orbital slots, providing high-data-rate transport services. The SPACEWAY non-geostationary Earth orbit (NGSO™) segment will consist of 20 satellites operating in MEO orbits. These additional satellites will increase overall SPACEWAY capacity, especially in high-demand areas. Both systems will operate in the Ka-band.

The global SPACEWAY system will provide coverage in four main regions: 1) North America; 2) Central and South America; 3) Europe, Africa, and the Middle East; and 4) Asia Pacific. Its "bandwidth-on-demand" capability will provide businesses and consumers with fast access to terrestrial networks, such as the Internet, intranets, and LANs. Operating two way via satellite, the system will use a family of terminals with dishes as small as 26 inches (66 cm) in diameter and provide uplink speeds as fast as 6 Mbps. Service is anticipated to begin in the first region as early as 2002.

SPACEWAY EXP will focus on the high-data-rate transport market using geostationary satellites operating from four orbital locations. SPACEWAY NGSO will add to overall SPACEWAY system capacity, providing advanced interactive broadband multimedia communications services in high-traffic markets globally. It will provide a wide range of broadband data rates operating through a family of small terminals. The SPACEWAY NGSO constellation will consist of four planes with five satellites in each plane, inclined at 55 degrees with respect to the equator and in circular orbits at an altitude of 10,352 km.

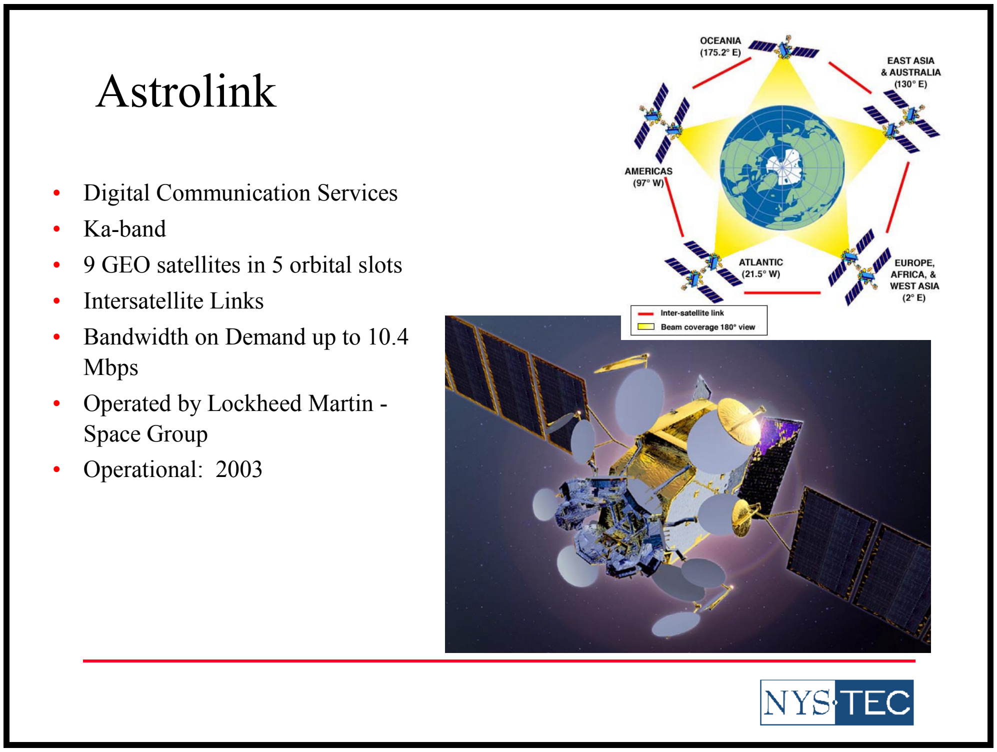

Figure 49, Astrolink System

Lockheed-Martin's Astrolink will enable global users to perform multimedia applications over virtual private networks (VPNs) at high data rates.

Astrolink will be a new communications network employing advanced satellites to provide digital communication services anywhere in the world. Astrolink is being designed with built-in security mechanisms to provide privacy of communications and positive user authentication and validation. System access and user-to-user authentication will be provided through public key and smart-card technology. Optional session encryption will be available depending on local regulations. Users will have seamless connectivity to both public and private networks with a wide range of choices in service levels and user data rates. Bandwidth will be allocated on demand; users pay for what they use without the fixed cost of leased lines.

The space-based component of Astrolink's network will consist of nine Ka-band satellites in a global constellation. These nine satellites will occupy five orbital slots (pending ITU coordination). The first launch is scheduled for 2001, and the system will be operational with the first satellite. Global coverage will begin when the next four satellites are up. The remaining five satellites will be added to meet later demand.

Each satellite will have 6-Gbps capacity. Intersatellite links will be optical, with a 440-Mbps data rate.

5.2.4 Examples of VSAT (Very Small Aperture Terminal); Gilat/GE SkySurfer System, Hughes Global Services.

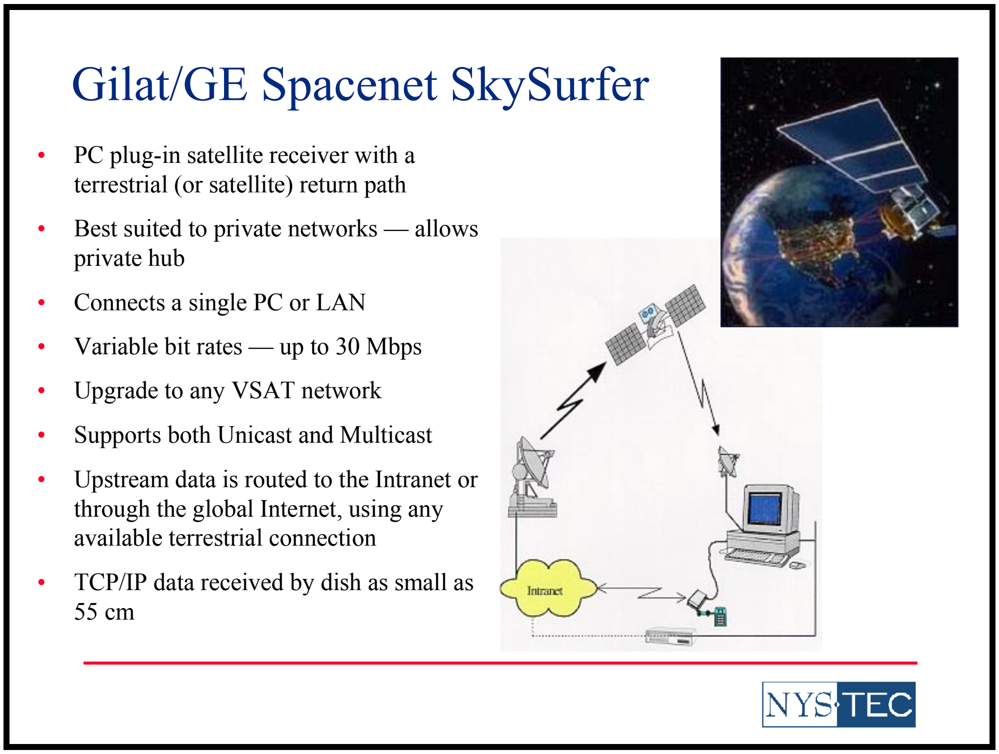

Figure 50, SkySurfer System

SkySurfer, a PC-based satellite receiver suited for private IP networks, routes high-bit-rate traffic via satellite and utilizes a terrestrial (or satellite) return path. The SkySurfer hub, typically located at company headquarters, provides users with a 2-Mbps channel for IP traffic. A minimum of 500 remote sites are needed to make this system cost effective. Intranets (IP-based private networks based on Web technology) are easily deployed using VSATs. SkySurfer can provide a fast T-1/E-1 (1.544/2.048 Mbps) overlay to any existing or new corporate Intranet. SkySurfer fits in the PCI slot of the user's desktop or LAN server. Using the overlay technology, each remote connection can obtain a T-1 speed access, which enables extensive use of video and data applications without affecting Intranet "mission-critical" data. Live video can be delivered at MPEG (Moving Pictures Expert Group) quality to each user without overloading network resources. The corporate Intranet Web can be accessed at speeds reaching 2 Mbps.

With SkySurfer VSAT, Gilat provides an interactive business television application. Real-time MPEG video quality is delivered to the desktop or to a TV screen. High-resolution MPEG files can be re-played locally. Using the video in conjunction with the interactive data channel, Gilat delivers a full turnkey solution for distance-learning use.

Using the SkySurfer, any internet service provider (ISP) can offer its subscribers a high-speed alternative for accessing the Internet — SkySurfer VSAT. The amount of resources and related investments can be tailored to meet local requirements. Multimedia-rich world wide web

(WWW) pages can be downloaded through any user's PCI receiver card under Windows 95, at data rates of up to 400 Kbps. This is the fastest Internet-access technology widely available today. Installing the card in a local-area network (LAN) server allows the use of the LAN as a fast Internet gateway.

Figure 51, HGS-1 System

Formerly known as AsiaSat 3, this satellite was launched Christmas Day 1997; but, due to a malfunctioning launch vehicle, the satellite was left in an unusable, highly elliptical orbit. Insurers declared it a total loss. Hughes Global Services, Inc., (HGS) obtained title in April 1998 to the fully functional satellite, an HS 601HP model built by Hughes Space and Communications Company (HSC) and renamed the HGS-1. HGS-1 successfully completed an historic mission that sent it around the moon twice to reposition it into a useful orbit. It is currently in an inclined geosynchronous orbit over the Pacific Ocean.

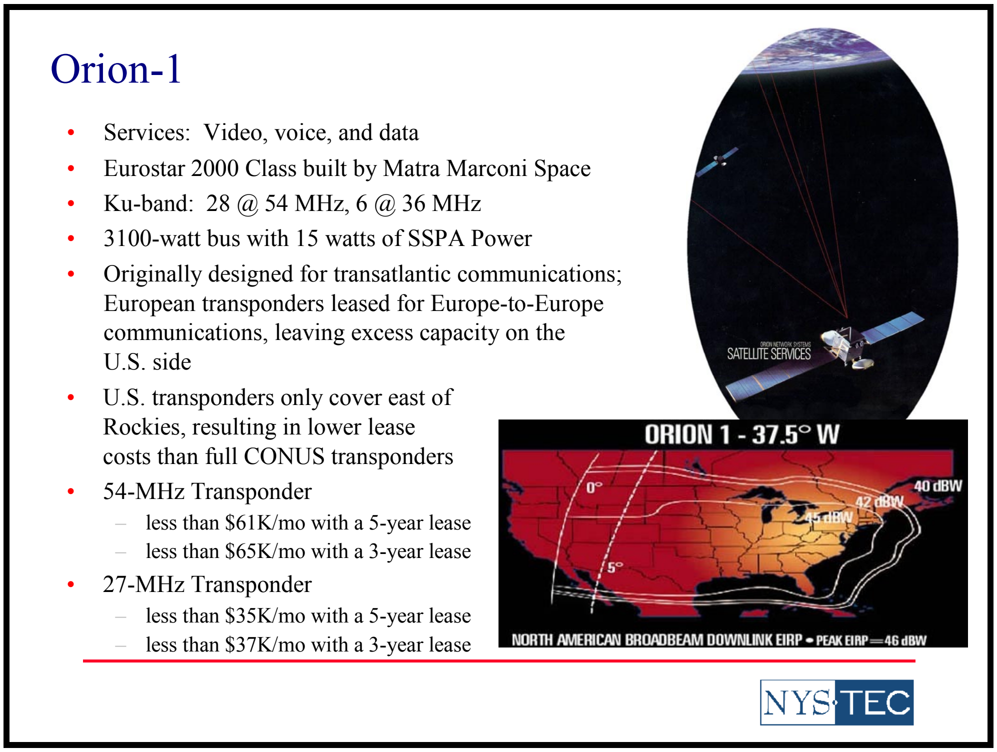

Figure 52, Orion-1 System

Orion-1 was designed for transmitting data across the Atlantic Ocean, but it was found that there was more interest in Europe-to-Europe transmission. Much of the capacity on the European transponders was used for intra-Europe transmissions, leaving unused capacity on the U.S. transponders. It is difficult to sell space on these transponders for intra-U.S. transmissions, because the transponders do not cover all of the U.S. In order to make these transponders more attractive, Orion has significantly reduced the price of leasing these transponders. The prices listed above could be easily negotiated down.

New York State is fully covered by Orion. The effective isotropic radiated power (EIRP) in New York is between 45 and 47 dBW. Transponders are all digital. Orion is a simple "bent-pipe" transponder. The user provides all the ground station personnel and hardware.

This system offers little to the County. As an part of an LMR system, special products would have to be developed at costs well beyond provisioning an "off-the-shelf" system; therefore, application here of this particular technology is not practical. To date, no one in the world has looked to Orion-1 as a LMR solution.

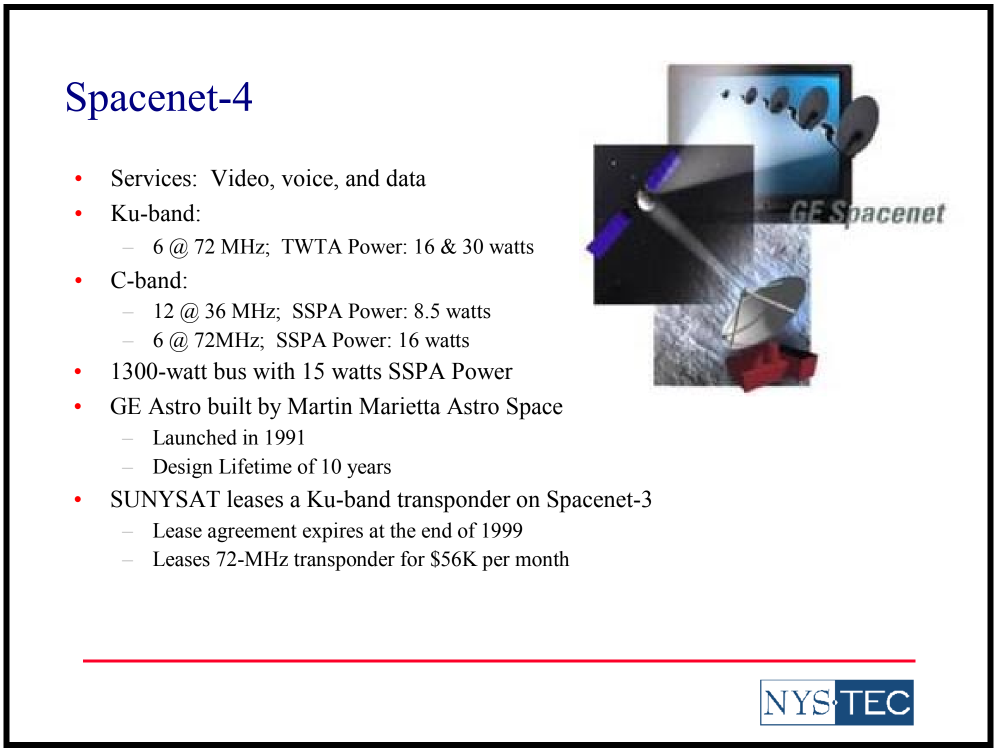

Figure 53, Spacenet-4 System

TWTA = Traveling Wave Tube Amplifier

SSPA = single-sideband power amplifier

Spacenet-4 is an older satellite nearing the end of its lifetime, which means transponder space is cheaper. Spacenet has indicated that Spacenet-4 will be operational beyond its 10-year life expectancy, to the year 2004.

Spacenet-4 is currently located at 101°W, and is collocated with several of Hughes' high-power direct Broadcast TV satellites. This system is strictly usable for fixed operations, not mobile.

5.3 General Summary of Satellite Communications Systems

A summary table of voice systems follows in Table 9.

Table 9, Summary of Voice Satellite Systems

Item System	Iridium	Globalstar™	ICO	Ellipso™	SkyCell
Company	Motorola	Loral/QUALCOMM®	ICO Global Communications	Mobile Communications Holdings	American Mobile Satellite Corporation
Number of Satellites	66	48	10	14	1
Orbital Planes	6 Circular Polar 86.5°	8 Circular Inclined 52°	2 Circular Inclined 45°	2 Elliptical Inclined 116.6°	1
Orbital Altitude (km)	780 (LEO)	1,400 (LEO)	10,355 (MEO)	520 to 7,846 (MEO)	35,780 (GEO)
Satellites per Plane	11	6	5	4 per elliptical; 6 per equatorial	1
Beams per Satellite	48	16	163	61	1 satellite with 4 spot beams
Costs	Not in Service	$1.50 - $2.99 per minute; $1,500 per user handset.	$1.00 - $2.00/ minute; $1000 handset costs	$0.50 a minute	$0.95 to $1.5 per minute with transportables about $3000
Dispatch	No	TBD	No	No	Yes

5.4 Specific Systems That Have Limited Use in Public Safety

This section details technologies that have been employed in public-safety applications.

5.4.1 American Mobile Satellite Corporation SKYCELL System

SKYCELL, a satellite service operating in the L-Band of the radio spectrum, provides voice and data services to the continental United States, Alaska, Hawaii, the Caribbean, and coastal areas. SKYCELL supports telephone interconnect, two-way radio features, STU-III service, fax, and circuit-switched data. Some of the Features of the SKYCELL system include[40]:

- 100% digital communications,
- PTT two-way radio communications for workgroups,
- Full-duplex voice communications,
- Landline access to mobile talk groups,
- Direct dialing for full telephone calling for national and international calls,
- Voice mail, call-waiting, call-forwarding, conference calling, and call-barring,
- Credit and debit card services,
- 4800-bps data transmission,
- Group III fax,
- 24-hour access to customer-service representatives, and
- 24-hour directory-assistance and emergency-referral services.

The various features and configurations provided by SKYCELL are summarized in Table 10. Real-world experience with SKYCELL by public-safety has been mixed at best. For example, the New York State Police has been using SKYCELL to temporarily augment a site that is off-line. The NYSP has not been happy with the system's ability to maintain its link during voice communications. This includes getting obstructed by geophysical terrain elements.

[40] American Mobile Satellite Corporation SKYCELL product literature online: http://www.satellitetelephone.com/services.htm

Table 10, SKYCELL Features and Configurations

Configuration	Features
Nationwide Two-Way Radio Network with SKYCELL Dispatch	• Provides operation similar to two-way radio • Real-time voice services • Digital broadcast dispatch • Instant workgroup connectivity • Full access to all SKYCELL satellite communications features • Priority-one emergency contact • Customizable talk group assignments • Call types: ▪ Private-mode talk group ▪ Dial-in/dial-out dispatch ▪ Broadcast mode talk group
Satellite Telephone Services	• National and International calling • Ability to place toll-free calls • No roaming charges • STU-III support
System Configurations	• Land-Mobile Service • Transportable Service • Fixed-site Service • Aeronautical Service

5.4.2 TMI Satellite System

Similar to AMSC, TMI Communications, a satellite service operating in the L-Band of the radio spectrum, provides voice and data services to the continental United States, Canada, Alaska, Hawaii, the Caribbean, and coastal areas. TMI supports telephone interconnect, two-way radio features, STU-III service, fax, and circuit-switched data. Some of the features of the TMI system include.

- TMI's Packet Data Service designed to support wireless data applications like:
  - Fleet management
  - Automatic Vehicle Location (AVL)
  - Supervisory Control and Data Acquisition (SCADA);
- 2-way data messaging;
- credit card verification;
- electronic mail; and
- database query and information retrieval.

The TMI Packet Data Service network is an open system, providing a throughput of approximately 1.5 kbps inbound and 3 kbps outbound. It is economical and technically efficient for applications that send small amounts of data (<1000 bytes) or have a large number of remote terminals.

The two basic TMI Packet Data Service offerings are:

- Basic Asynchronous - provides a means for low-cost information retrieval or command of asynchronous data devices such as data loggers, and
- Basic X.25 - provides a means of establishing host-to-communicator or communicator-to-communicator packet data connections using the ITU-T X.25 interface protocol.

The TMI Packet Data Service network is part of the PSTN and has its own Data Network Identification Code (DNIC). An X.25 gateway provides connectivity from the TMI Wireless Packet Data Network to connect to other networks (through Datapac) worldwide. An IP gateway supports Internet Protocol connections to the Internet. What makes TMI even more interesting to the County than AMSC and its SkyCell product offering is TMI's packet data equipment and services.

Of further interest to the Tompkins County is the TAMS service offered by TMI Communications. TAMS can provides timely and accurate position as well as telemetry-like alarm sensors and will report the data over the Internet. This is useful for tractor trailers, rail cars, and fleet vehicles. This reporting service can provide regularly scheduled position reports of vehicles equipped with GPS receivers. This reasonably priced equipment and service could be useful to the County as a way to quickly deploy a location system without having to build out any new infrastructure within the existing VHF system. Further, with such a system serviced by a geosychronous satellite, the coverage is nearly ubiquitous.

TAMS having been built on Internet accessibility makes interfacing into Communications Center operations simpler then having to deal with a proprietary non-standard interface.

Generally the features and configurations offered by TMI are similar to AMSC — with the most notable exception being that of the packet data equipment and services as well as the TAMS system.

Table 11, TMI Communications Features and Configurations

Configuration	Features
Nationwide Two-Way Radio Network with TMI dispatch	• Provide operation similar to two-way radio • Real-time voice services • Digital broadcast dispatch • Instant workgroup connectivity • Full access to all TMI satellite communications features • Priority-one emergency contact • Customizable talkgroup assignments • Call types: ▪ Private mode talkgroup ▪ Dial-in dial-out dispatch ▪ Broadcast mode talkgroup
Satellite Telephone Services	• National and International calling • Packet Data • Basic Asynchronous • Basic X.25 • Ability to place toll free calls • No roaming charges • STU-III support
System Configurations	• Land Mobile Service • Data Service • Transportable Service • Fixed-site Service • Aeronautical Service

5.5 Drawbacks of Satellites

Drawbacks of satellites include: the potential for failure, the transmission time, and the expense. The satellite is often viewed as the single point of failure in the system, but this need not be true. On-orbit satellites are quite reliable, and service providers are now parking multiple satellites in an orbit to provide increased capacity. Should one satellite fail, other satellites in that slot may pick up the traffic. This guaranteed service, however, comes with a premium. Similar guaranteed uplink service must be considered and contracted. Transmission time may be a bigger issue for this application. A single hop through a satellite can take anywhere from 0.25 to 0.5 seconds, and call setup times can range from 5 to 50 seconds and more. This is well beyond the maximun transmission delay allowed in some critical public-safety communications.

Costs extending into $1 to $3 per minute and more in some cases would be cost prohibitive for the call traffic that the County's public-safety users would require to get the job done.

Satellite providers offer benefits such as wide-area coverage in rural or remote areas where terrestrial service has not been built out or may never be extended, particularly for fixed location operations, such as at a command center. Its utility for users "on the move," such as public-safety field personnel, is limited.

- *Long call set-up times*. In public safety applications, users must get calls through quickly. The PSWAC committee (discussed earlier) recommended less than ½-second call access.

- *Long delay times in transmissions severely hinder two-way voice communications.* Related to the fundamental requirement of fast call throughput is transmission delay, which is also an issue with satellites in public-safety applications. The ½-second call access applies here too. For satellite systems that are geosychronous, this is just about impossible to achieve because of the basic physics (GEO satellites always face about a 45,000-mile path length).
- *Direct line of sight to the satellites required, thus no in-building coverage*. Direct line of sight is clearly not practical in public safety, where public-safety providers must work under trees and on the side of hills, etc.
- *Bulky mobile and portable user equipment*. Much of public-safety work centers on the user dismounted or away from a vehicle where a portable radio is more practical to use. Public-safety personnel can not be expected to carry and set up a briefcase device every time they need to make a call.
- *Expensive per minute charges for service*. Satellite systems essentially are commercial carriers with infrastructure in the sky. They can provide subscriber equipment that is relatively the same cost as LMR subscriber equipment, but they must pay for that infrastructure in the sky. It is usually in the business plan to make up that cost of deploying an expensive orbital infrastructure by the reoccurring costs (minutes for voice calls, or cost per character for data) that are charged to their clients.

Satellite systems do offer partial solutions to public-safety groups. Satellite systems can get communications connectivity going in emergency situations where terrestrial infrastructures have been taken down (e.g. by earthquakes). The issue with using satellites in public safety is trying to employ them as a *total solution*; there the practicality is very doubtful.

6. Wireless Communications and Human Health

This section is concerned with the biological effects of exposure to electromagnetic fields, in particular radio-frequency (RF) fields as they pertain to radio siting.

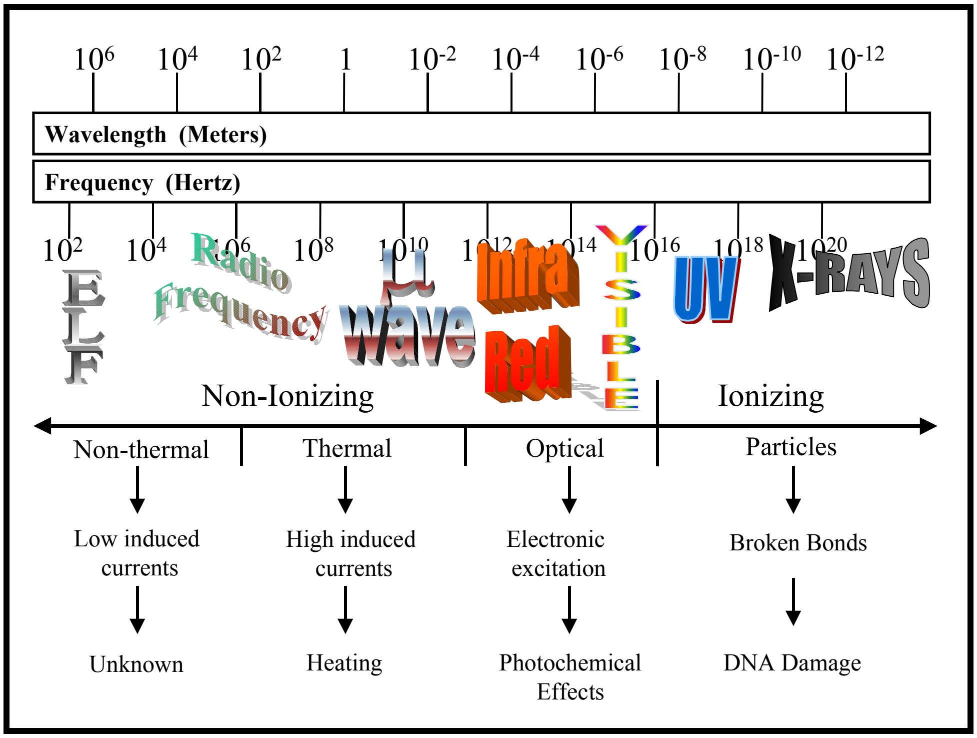

Figure 54, Non-Ionizing and Ionizing Electromagnetic Spectrum

6.1 Biological Effects of RF Exposure

There is a great deal of literature on RF exposure. There are more than 1000 reports in peer-reviewed publications on a wide variety of exposure conditions. There is extensive clinical literature on RF effects.

The known biological effects of RF exposure are due to thermal-energy conversion. This occurs when the RF energy is absorbed by the body and turned into heat energy. The thermal effects on the body are proportional to the rate of absorption, relatively independent of frequency within the 30-MHz to 300-MHz band and are not cumulative with time. Of critical importance in regards to health and radio-siting exposures that do not result in elevated temperature, there is no reproducible evidence for cancer, effects on the immune system, or effects on growth or development[41].

[41] *Wireless Communication Antennas and Human Health,* Practical Siting for Wireless Communications Antenna and Towers, Feb 1998, Dept Engineering, University of Wisconsin-Madison, John E. Moulder, Ph.D. Professor of Radiation Oncology, Medical College of Wisconsin.

6.2 RF Safety Standards

This section details, for interested parties in the County that would like them for reference, the national RF safety standards. The methodology for measuring the RF fields is not given here. The methodology for measuring RF fields was developed by the Office of Engineering and Technology of the FCC and is published in OET Bulletin 65[42].

The dominant standard in the U.S. and Internationally is ANSI/IEEE[43] C95.1. The Federal Communications Commission (FCC) adopted an RF standard in 1996 that is based on the ANSI standard. The most relevant portion of this standard, for this discussion, is the Subject Absorption Requirement (SAR) of:

- Keeping whole-body SAR below 0.08 W/kg and
- Keeping partial-body SAR below 1.6 W/kg.

Further, determining if a potential health hazard may exist with a given transmitting antenna is matter of finding several important factors. These factors include answers to the following questions:

- What is the frequency of the RF signal being transmitted?
- What is the operating power of the transmitting station, and what is the actual power radiated from the antenna?[44]
- How long will someone be exposed to the RF signal at a given distance from the antenna?
- What other antennas are located in the area, and what is the exposure from those antennas?

6.2.1 <u>FCC Authority To Regulate</u>

The FCC regulates all frequencies in which cellular, PCS, and land-mobile wireless users operate. Further, Section 1.1310 of the FCC's rules establishes maximum permissible exposure (MPE) limits for people.[45] The FCC derives its power from Congress. The rules of the FCC are, in effect, the law. Further, as these rules are generated by the FCC with the authority of Congress, they are Federal law that supercedes State or local laws and ordinances. In these matters, the FCC has total authority to regulate public health and safety, and it would literally take an Act of Congress to change that. All these rules, on public health and safety, started as proposed rules that have undergone long comment periods and opportunities for public review and comment. Under this process, when the proposed rules became rules, they went into effect with the strength and authority of laws enacted by Congress.

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[42] OET Bulletin 65, Edition 97-01, August 1997.

[43] ANSI: American National Standards Institute, IEEE: Institute of Electrical and Electronics Engineers.

[44] Power travels from a transmitter through cable or other connecting device to the radiating antenna. "Operating power of the transmitting station" refers to the power that is fed from the transmitter (transmitter output power) into the cable or connecting device. "Actual power radiated from the antenna" is the transmitter output power <u>minus</u> the power lost (power losses) in the connecting device <u>plus</u> an apparent increase in power (if any) due to the design of the antenna. Radiated power is often specified in terms of "effective radiated power" or "ERP" or "effective isotropic radiated power" or "EIRP".

[45] Thus, by way of illustration, it takes 100,000 milliwatts of power to fully illuminate a 100-watt light bulb.

6.2.2 Maximum Permissible Exposure (MPE) Limits

The MPE values vary by frequency because of the different absorptive rates of the human body by different frequencies and RF fields. Section 1.1310 sets MPE values, or limits, in terms of "electric field strength," "magnetic field strength," and "far-field equivalent power density" (power density). Generally, the most relevant measurement is power density. The MPE limits for power density are given in "milliwatts per square centimeter" (mW/cm^{2}). One milliwatt equals one thousandth of one watt (1/1000 of a watt).[46]

Because it is not practical to measure the exposure of every square centimeter of the body, the FCC limits on RF emissions are determined by "spatially averaging" body exposure over a projected area of a human body.[47]

6.2.3 FCC Limits for Maximum Permissible Exposure (MPE)

These RF exposure levels are set by frequency, not the applied technology. In this report, various technologies have been discussed. To understand the exposure limit of a wireless technology, one only need to know the operating broadcast frequency, or frequencies. For example, simulcast transmissions are not any more limited or relaxed than multicast transmissions — all the radio sites must comply to these exposure limits regardless how they work.

1/ Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

2/ Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

NOTE 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for

[46] Thus, by way of illustration, it takes 100,000 milliwatts of power to fully illuminate a 100 watt light bulb.
[47] This concept is discussed in the FCC's OET Bulletin 65.

occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply, provided he or she is made aware of the potential for exposure.

NOTE 2: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or cannot exercise control over their exposure.

7. Tompkins County Public Safety Communications and Commercial Carriers

This section explores some of the current environment of the County in regards to having commercial carriers provide communications for the County.

Co-location Income

The reality is that the County is an area supporting about 100,000 people. Commercial companies have already completed some site development. Co-location income in an area that would primarily provide rural wireless service is not going to demand the same types of recurring monthly fees as one would expect in urban communities. However, there is income to be realized, and it can be used to offset costs, but this income will probably never take in a major portion of the overall costs for a new radio system with new technology, as is shown in Table 12.

Table 12, Project Site Income to the County

Service	MI/Site	5 Site System/ Month	Income/Annum
Cellular	$1000	$5000	$60,000

The assumptions made above assume that five of the sites in a future system will be located in a populated enough area of the County that a cellular (or PCS) carrier would be interested in co-locating on them. For these five sites to generate $1000 per site they may need to have two cellular (or PCS) carriers on them. This means it could take a number of years to generate $60,000 per year income from the system for co-location.

Over a ten-year period this is $600,000. This is assuming best-case conditions, which could take a few years for the County to realize. As this is worthwhile income for the County to pursue over a ten-year period, it still does not represent a significant portion of the overall costs of building and maintaining the system.

Other possible income may be derived from future wireless technologies like Local Multipoint Distribution Service (LMDS) and others still emerging.

Voicestream (formerly Omnipoint)

There has been much discussion in the commercial telephony community that Voicestream/Omnipoint has been trying to expand into western New York. Thus, a possible co-location tenant of the County would be Voicestream.

Omnipoint currently provides limited upstate coverage, as depicted in Figures 55 and 56. Given Voicestream's planned buildout, sites in the County may well be attractive to the provider. As with the other cellular and PCS providers, this service matches closely with population centers and the thoroughfares connecting them. Little coverage is provided outside of these areas. Sources inside the NYS Thruway (which shares tower locations with Voicestream) indicate that the planned coverage buildout depicted below has been delayed and, in fact, may not happen for some time. This has been verified by a Voicestream source, which indicated that the funding for the western coverage expansion is currently on hold.

Thus, the westernmost coverage provided by Omnipoint along the Thruway corridor only extends to Port Byron. From these maps, also notice that coverage does not extend very far off of the Thruway (I-81 or I-87).

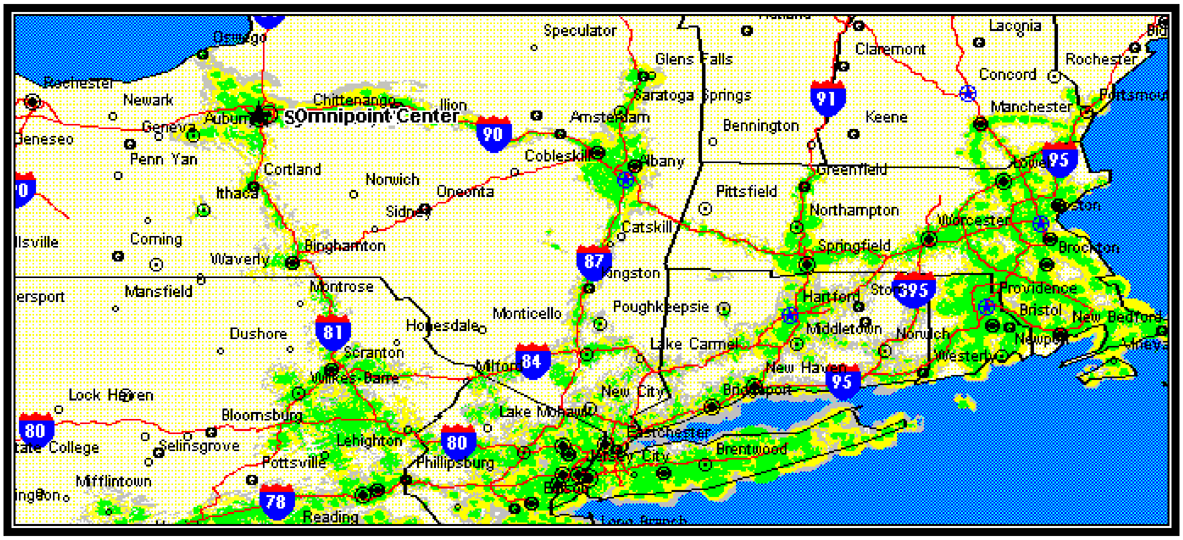

Figure 55, Voicestream Current Coverage

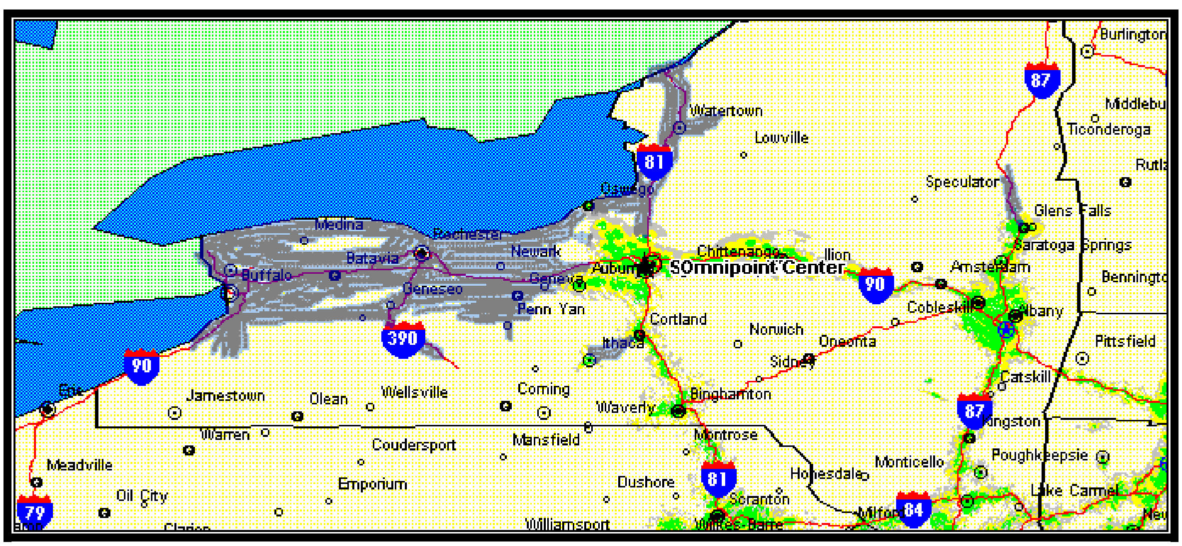

Figure 56, Voicestream Planned Coverage

Verizon, NEXTEL and Others

Carriers have some sites already developed in the County. These sites should be considered because they have been developed using modern radio-site-development practices and they represent areas on which the County could co-locate. One such example is the Verizon site at Bull Hill Road. As time goes on, the County will be more likely co-locate on radio sites that exist and are owned by a wireless carrier instead of getting a carrier to co-locate on a county site.

What may be at issue with this is the fact that these sites are already engineered for the occupants that they serve now. Future technology like 800-MHz digital simulcast will require microwave point-to-point equipment to link the site in order to work well. Preexisting sites may require extensive (and expensive) re-engineering to accomplish this.

7.1 Public Safety Communications Technology

Recall the high level requirements of public safety systems:

- Point-to-Multipoint and Voice Dispatch (Req. 1)
- Fast Call Throughput (Req. 2)
- Ubiquitous coverage (Req. 3)
- Priority Calling, and Call Preemption (Req. 4).

Combining priority calling and call preemption is done here for simplicity and because both are based on equipment generating and systems recognizing signaling.

Table 13, Satellite Technologies

Satellite Technology						Costs	
Carrier	**Req 1**	**Req 2**	**Req 3**	**Req 4**	**Ave.**[48]	**Start**[49]	**Re-oc**[50]
SKYCELL[51]	3	1	4	0	2	$1.7M	$100k
Iridium	0	2	4	0	1.5	NA[52]	NA
Globalstar™	0	2	4	0	1.5	$2M	$100k
ICO	0	1	3.5	0	1.13	$2M	$100k
Ellipso™	0	2	3	0	1.25	$2M	$100k

Table 14, Radio Common Carrier Technology

Radio Common Carrier Technology						Costs	
Carrier	**Req 1**	**Req 2**	**Req 3**	**Req 4**	**Ave.**[53]	**Start**[54]	**Re-oc**[55]
Voicestream	0	3	1	0	1	$50k	$75k
NEXTEL	3	3	1	0	1.75	$50k	$75k
Verizon	0	3	1	0	1	$50k	$75k

Further, while provisioning public-safety personnel with equipment and network support that best fits the requirements is everyone's goal, economic scarcity must be a factor in that the system has to be economically obtainable.

[48] Ave.: Average of requirement weighted values.
[49] Start: Start up or one time costs.
[50] Re-oc: Re occurring costs all based on monthly re-occurring costs if applicable.
[51] Most, if not all, of the particulars for SKYCELL are assumed to be similar (in voice) to TMI.
[52] System no longer available, costing not applicable
[53] Ave.: Average of requirement weighted values.
[54] Start: Start up or one time costs.
[55] Re-oc: Re occurring costs all based on monthly re-occurring costs if applicable.

Generally these systems will be weighted on a scale of 0 to 5, 0 being totally non-compliant and 5 being totally compliant. Further, when a technology has a system within it that is compliant, it will be given the best value even if most other systems are not. An example of this occurs with satellites: most do not have point-to-multi-point voice dispatch; however, SKYCELL does offer it, when almost all other satellite systems do not.

Combined Results of Technologies						Costs	
Technology	**Req 1**	**Req 2**	**Req 3**	**Req 4**	**Ave.**[56]	**Start**[57]	**Re-oc**[58]
SKYCELL[59]	3	1	4.5	0	2.13	$1.7	$100k
NEXTEL[60]	3	3	1	0	1.75	$50k	$75k

Costs are based on what it would take to provision Tompkins County public-safety personnel. These "solutions" may well cost less than a land-mobile radio system, but they all fall very short of the requirements. Recalling that an average value approaching the ideal of five is more desirable, these solutions clearly are not total solutions. Commercial carriers may offer partial solutions in some areas, but their existence does not eliminate the need for a land-mobile radio system.

56 Ave.: Average of requirement weighted values.
57 Start: Start up or one time costs.
58 Re-oc: Re occurring costs all based on monthly re-occurring costs if applicable.
59 SKYCELL, American Mobile Satellite Corporation.
60 NEXTEL does provide Point to Multipoint and Voice Dispatch