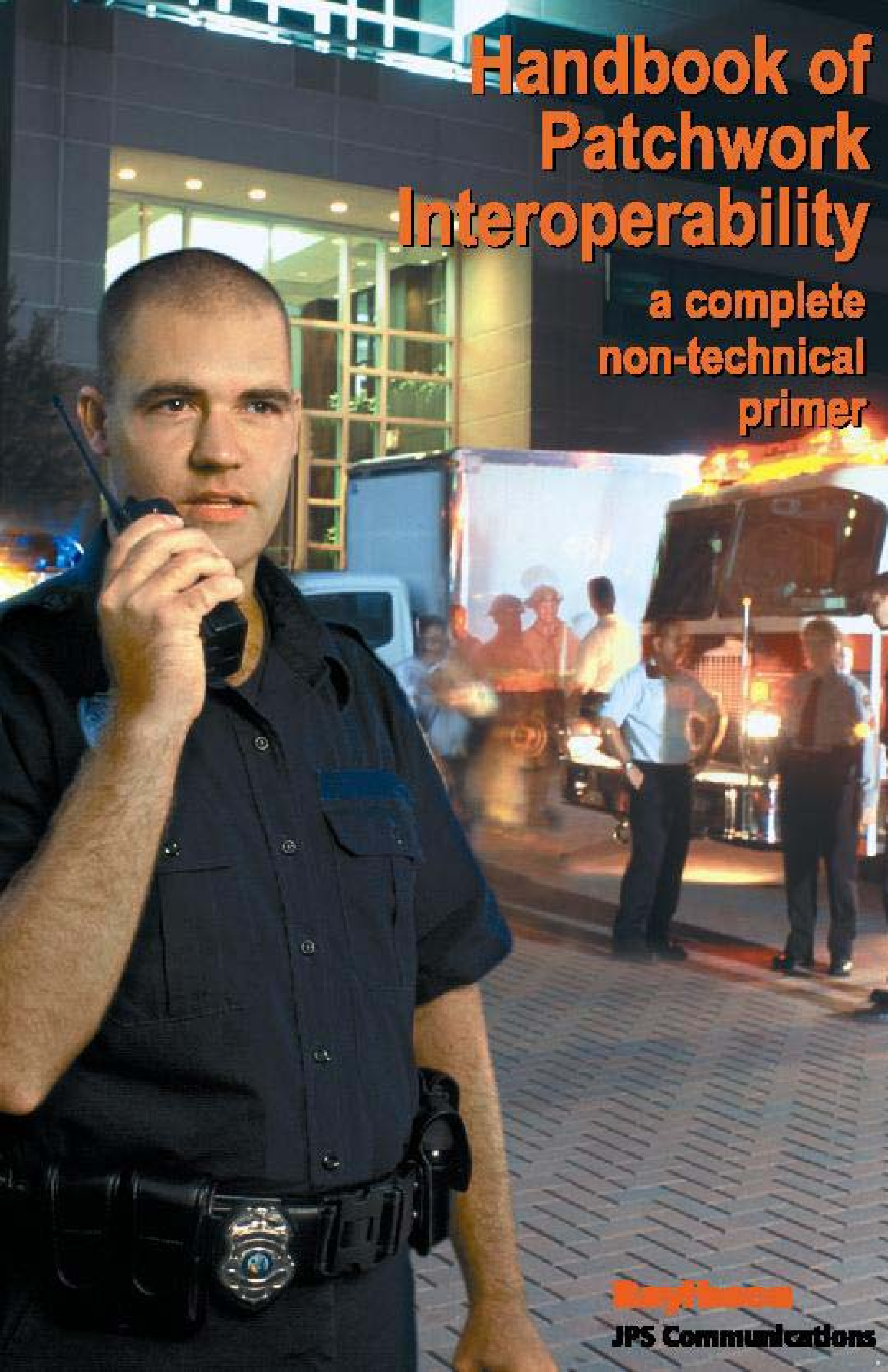

Handbook of Patchwork Interoperability

a complete non-technical primer

JPS Communications

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Patchwork Interoperability

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Revision 2.11
June 2004

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This handbook is an introduction into all aspects of patchwork interoperability: applications, equipment, features, procedures, and potential problems. JPS Communications is the recognized leader in Patchwork Interoperability Solutions since 1988. This handbook is a compilation of 15 years devoted to solving interoperability problems and perfecting interoperability solutions. It is based on experience from actual field deployment by Public Safety Agencies across the country and around the world.

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Glossary

2-Wire Device	Equipment that carries both the transmit signal and the receive signal on the same pair of wires.
4-Wire Device	Equipment that has separate lines for transmit and receive audio signals. One pair for TX, and another for RX, totaling four wires.
COR	Carrier Operated Relay - A receiver signal that indicates that a carrier or signal is being received and the receiver is unsquelched. Same as COS.
COS	Carrier Operated Squelch - See COR.
DTMF	Dual Tone Multi Frequency - The standard touch-tone telephone dialing method sends DTMF characters over the PSTN line.
DSP	Digital Signal Processing (or Processor). DSP algorithms are software programs that perform various functions on audio signals, such as Noise Reduction or Voice Modulation Recognition.
Full Duplex	All parties of a conversation can speak and be heard at the same time (simplified definition).
GUI	Graphical User Interface - A computer program that uses icons and images rather than text.
Half Duplex	Only one person in a conversation can speak (and be heard) at a time (simplified definition).
Hang Time	A system with hang time will remain in the transmit mode for the duration of the set hang time beyond the time indicated by any keying inputs. The hang time prevents transmitter unkey during brief pauses in the transmission.
Key	To key a transmitter means to cause it to transmit.
LED	Light Emitting Diode.
LMR	Land Mobile Radio.
MOU	Memorandum Of Understanding – A legal agreement between interoperability system users that describes conditions for interoperable communications.
Mute	To quiet or inhibit audio.

PCB	Printed Circuit Board.
Phone Patch	A device that interfaces a two-wire telephone system to a four-wire radio
PTT	Push-to-Talk - An active PTT signal causes a transmitter to key.
RoIP™	Radio over Internet Protocol (compare to VoIP) not only converts voice to a digital format that can be sent over the Internet or other IP based network, but also converts the PTT and COR signals that are essential for seamless radio interoperability. Also included are extra delay and jitter compensation.
RX	Receive, Receiver or Receiving.
SOP	Standard Operating Procedure – The SOP complements an MOU by detailing the procedures and protocols that guide interoperable communications.
Squelch	A means of detecting audio and causing some action when it is present, such as keying a transmitter or unmuting an audio path.
TX	Transmit, Transmitter or Transmitting.
VMR	Voice Modulation Recognition - A circuit or algorithm that is activated only by spoken words and not by tones, noise, or other audio information. Within an Interoperability System, a VMR signal is used to trigger the PTT input of cross-connected devices.
VoIP	Voice over Internet Protocol - Provides a method of converting voice to a digital format that can be sent over the Internet (or any data network using the Internet Protocol) without the need for traditional telephone lines from a phone company.
VOX	Voice Operated Xmit (Transmit) - A circuit or algorithm that causes an output to be triggered when incoming voice (or other audio signal) exceeds a set threshold. Within an Interoperability System, a VOX signal is used to trigger the PTT input of cross-connected devices.

1 Patchwork Interoperability Defined

1.1 What Is Patchwork Interoperability?

A quick and simple definition of interoperability is:

The ability of any public-safety official to talk to whomever they need to, whenever they need to, when properly authorized.

Interoperability is required because without it, the large number of different types of communications systems currently in use can't work with each other, making it very difficult for the users of different systems to converse. Normally, one type of radio ignores the signals of all other radio types, and a telephone user usually can't talk over a radio.

Interoperability allows these disparate communications systems to work together. With interoperability, the user of a VHF radio can talk freely over that radio to another radio user who is operating a UHF radio. Or these two radio operators can engage in a conference call that also includes a Nextel subscriber, a SATCOM user, and someone on an 800 MHz Trunked talk group.

If each system always heard every other, the outcome would be complete chaos. A competent Interoperability System ties together the proper systems when needed and no longer than needed. Pre-agreed procedures ensure that cross-connections between systems are always properly authorized.

Patchwork Interoperability takes existing communications systems and ties them together with minimal additional equipment and minimal disruption to ongoing communication. It helps you make the most of your existing communications infrastructure.

1.2 Why Is It Needed?

For many years, public safety professionals have been aware of the need for Patchwork Interoperability. In almost every post-incident "after action report", whether following 9/11 or twenty years prior, you will find the inability to communicate listed as a critical problem or as an item requiring future attention.

Many conditions require interoperability, but of particular interest are emergencies and disasters. These incidents bring together a wide variety of different experts and professionals, depending on the situation. They include "First Responders", as well as others who are brought in later, among them medical personnel, police, firefighters, hazardous material experts, FEMA, FBI, etc.

When they show up on the scene, each group is likely to have a different type of radio or other communications device, with a whole lot riding on *quick and seamless* communication *between the appropriate people*. Effective Patchwork Interoperability allows these people to communicate with each other, with each group using its own communications gear.

"Quick and seamless" is crucial, because what happens at the beginning of the response to an incident can be the most important, and during this high stress time a single missed word can be catastrophic.

"Between the appropriate people" is key, because if all groups at the scene are simply tied in together, the resultant pandemonium will exacerbate the communications problems rather than alleviate them.

Another important feature of Patchwork Interoperability is that sabotage (or accidental damage) at one or two locations will have only minimal effect on overall communications. In contrast, failure at a single site could completely shut down an "all-encompassing" system, such as a large trunked system that controls all communications.

1.3 Evolution of Patchwork Interoperability

As important as interoperability is, how was this need handled before the design of electronic equipment to facilitate it? Essentially, one person was assigned to relay messages between one communications medium and another, first listening to one radio and then repeating the message into the other. This method has a reasonable potential for success when just one pair of radio systems need to be connected. However, in today's communication environment, with a wide range of systems in use, the likely result is faulty communication and a massive migraine.

Figure 1-1 Early Interoperability

1.4 Part Technical, Part Procedural

No matter how capable the Interoperability System, giving existing communications systems the ability to cross-connect with each other is only half the battle. Of equal importance are proper procedures and agreements that describe by whom, how, and when the equipment is to be used. Furthermore, if all system users aren't fully trained, and the equipment and procedures aren't regularly exercised, the system won't be ready when it's truly needed.

The best current technology won't resolve the interoperability problem unless all of the agencies involved work together. The common thread that binds all interoperability successes is a cooperative vision shared by all participating agencies, backed up by agreements and policies that mandate how the system will be used when the need arises.

Important procedural aspects of effective interoperability will be described throughout this handbook. Chapter 9 is devoted entirely to "Memorandums of Understanding" (MOU) and a "Standard Operating Procedure" (SOP).

An **MOU** is a legal agreement between systems users granting permission (under specified conditions) for all parties in the system to cross-connect their radios and other communications systems.

An **SOP** stipulates the protocols and procedures that govern all interoperability cross-connections.

1.5 Important Features That Make It Work

A Patchwork Interoperability System that provides quick and seamless interconnections between the appropriate people should have each of these features:

1.5.1 Connect Existing Communications Systems Together with Minimal Cost & Disruption

Patchwork Interoperability connects existing communications systems together. It ***does not*** mean replacing existing systems with a new one. The Patchwork Interoperability System should make maximum use of existing infrastructure (thereby reducing cost) while inflicting minimal disruption on existing communications.

Remember that an Interoperability System is most strongly needed during a disaster or some other unusual and unpredictable occurrence. The types of First Responders and outside experts who converge on the incident scene will vary, so there is no way to predetermine what types of communications systems will be in use (and in need of interoperability) during an emergency. Therefore, if an attempt to provide interoperability consisted of dismantling existing radio channels and installing a major trunked radio system, there would still be no provisions for communications with the outside agencies and experts who arrive to help.

1.5.2 Brings the Right People Together

Effective emergency communications occur when key personnel can talk with each other, not when entire radio systems are cross-connected. Otherwise existing communications can be disrupted, and the likelihood of untrained personnel confusing themselves and the critical experts is increased. Since comprehensive and experienced control is paramount, interoperability systems are primarily for incident commander use and secondarily for individual first/second responders.

A main point of convergence derived from successful Interoperability System implementations is that they should, whenever possible, facilitate communications between ***Tactical Communications Assets*** rather than entire radio systems. This means that they allow cross-connections between tactical trunking talk groups (set up for particular types of incidents), pre-determined tactical conventional channels, and mutual aid frequencies. The intent is to limit, as far as practical, the interoperability communications to those individuals who have operational responsibility for the particular incident.

1.5.3 Practice, Practice, Practice

An effective Interoperability System requires that all users be comfortable with system features and operation. This includes both the technical and procedural aspects. Regular demonstrations, practices, drills and exercises build confidence levels with all participants and expose any shortfalls in training, equipment, or procedures.

Mock disaster drills are a great way to test system and personnel readiness so that any deficiencies can be corrected before an actual disaster occurs. Previous events that took place before the Interoperability System was available can be re-enacted (this time using the system), to demonstrate its value.

Non-Critical use of the system allows everyone to develop confidence in it. Besides practice sessions, the Interoperability System can also be put into regular use during the following:

- The tracking of incidents that cross jurisdictional boundaries.
- Large sporting events or other entertainment venues and concerts or during parades and street fairs (for security at any large gathering)
- As a “radio intercom” during serious weather conditions

1.5.4 Quick Setup Capability

Actual disasters can’t be pre-scripted, so it’s crucial that the Interoperability System be capable of quick setup and operation. The most prudent course is to use the Interoperability System on a regular basis, to include mock disaster drills and training exercises. This ensures that the system is pre-configured to handle most emergencies, and that its operators are fully trained and ready to handle whatever surprises arise.

Since there’s no way to prepare for every real-world contingency, it’s also important that whenever a situation requires it, any new and unexpected radio model or communications system can be quickly integrated into the system.

One readiness method is to have spare communications ports available (referred to as ‘walk-up ports”), and a “cable cache” of radio interface cables on hand to quickly add a new radio to the system. It’s wise to also have some unterminated cables available to allow on-site creation of an interface to the truly unexpected radio or other device.

The Interoperability System, if computer controlled, should also have a means to quickly include the new radio or other communications medium into the computer program and optimize its interface.

1.5.5 Clear Command & Control Capability

During a disaster or other type of emergency it's important that professionals who need to speak to each other can do so. Even if all the proper procedural and training practices have been put into effect, maintaining control of the system is impossible unless an effective control interface exists.

The Patchwork Interoperability System must have an easy means of connecting the proper communications assets together. It's equally important that these cross-connections can be quickly dissolved as soon as they are no longer needed.

To accomplish this, the system should provide the means to:

- See at a glance who is connected to whom
- Monitor ongoing communications
- Quickly make and break cross-connections

1.5.5.1 Local Manual Control

These are controls built directly into the Interoperability Equipment (switches, keypad, display). Local manual control obviously requires that an operator stays available with the equipment during its operation. This method is acceptable for a quickly deployed small tactical system.

1.5.5.2 Local Computer Control

Local computer control, along with the means to monitor the audio of a selected set of system users, is usually a more effective alternative. A well-designed graphical user interface combined with a touch screen monitor is optimal. An intuitive GUI allows even untrained operators to quickly understand current system status and make desired changes.

With small tactical systems, it's best that the computer control supplement rather than replace the manual control, with the computer serving as a helpful aid rather than an operational requirement. With larger systems (more than a half-dozen ports), computer control is definitely preferred as it makes it easier to stay aware of current system status.

1.5.5.3 Remote Computer Control

It's often beneficial or necessary that an operator control the Interoperability System from a remote location, over a digital network, and an effective computer control implementation should allow both local control and network control.

Optimally, the remote capability should allow an operator to monitor and control more than one interoperability device, and allow multiple operators to monitor and control any interoperability devices connected to the network.

1.5.5.4 Important Control Software Features

Computers excel at quickly manipulating large amounts of data, and any Patchwork Interoperability control software should take advantage of this capability and provide the following:

- Store system configurations for later recall.
- Allow on-the-fly adjustments of interface parameters to optimize system operation as changing conditions warrant.
- Store a library of "system interface optimization templates" to allow instant optimization of new radios interfaced to the system. The need for this will be clear after reading Sections 2 and 3.
- Create a historical log of activity.

Computer control applications should include security features such as password protection and different levels of authorization (i.e., some users can only monitor, some can modify cross-connections, and some also have access to system setup parameters to allow on-the-fly optimization). It's important that only trained operators have access to important setup functions.

1.5.6 Scalability

The Interoperability System must be designed in such a way that increased coverage and functionality can be added to the initial portions of the system without the need for wholesale replacement of the initial system. The system must be capable both of quick short-term expansion (to meet sudden needs during unusual or unexpected occurrences) and long-term system expansion to meet growing needs for additional users and features. Scalability is explored in more detail in Section 6.

1.5.7 Available, Proven, COTS

When purchasing an Interoperability System, it's ill advised to consider anything without a proven track record. You want a system that has all potential problems ironed out and all unusual conditions accounted for. As can be seen in Section 3 and Section 4 of this handbook, there are a lot of potential pitfalls that can bring interoperable communications to a halt, as well as many extra features that can optimize the system's utility. What you can't afford is to discover an untested system's problems during emergency operation.

A COTS (Commercial-Off-The-Shelf) Interoperability System with a history of trouble-free operation during trying circumstances is the best value and the safe choice. Before purchasing, be sure to ask your vendor representative for examples of successful, operational, implementations and references of public safety professional and agencies that are using the equipment.

1.5.8 Project 25 Compatible

Most new communications purchases are migrating toward APCO 25 standards. The Interoperability System must have proven P25 compatibility and be capable of cross-connecting P25 radios with non-P25 radios and other communications systems.

1.6 Reliability

There are a number of reliability issues that should be considered:

- MTTR - Mean Time To Repair. The system should be modular in design so that a failed module can be easily identified and replaced.
- RTOS - Real Time Operating System. The core equipment (the main interoperability device) should not rely on a PC-based operating system. If the system includes computer control, the reliability problems of PCs probably can't be avoided. However, if the computer fails or must be rebooted, the core equipment should be unaffected.
- Avoid single points of failure. Build in redundancy when possible.
- Graceful recovery from power outages. What does the system do when its power fails? When the power then recovers? If it has an accompanying computer control system, what happens if the computer loses power; regains power?
- Distributed Design. The Distributed Design concept means that the failure of any individual component will not affect the performance of any other components. By definition, Patchwork Interoperability adds capability to existing systems and does not replace them- therefore if it fails standard communications are not disturbed. Wide Area Applications of Patchwork Interoperability Systems should be made up of a number of smaller systems connected together over a network. This is a good example of Distributed Design- the failure of any individual small system will not affect the operation of any others, and if the network itself fails, each of the systems can continue to provide interoperability to their local areas.
- Proven Track Record. Obtain references on the solutions you are considering. Emergency interoperable communications are not a good place to be a pioneer.

Figure 1-2 Interoperability Tamed

If this is your introduction into the major concepts of interoperability, it may seem a bit overwhelming to specify a system that meets all of the criteria mentioned. Don't worry, Patchwork Interoperability will be explained from the ground up with minimal technical jargon.

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2 Solutions Overview

Some basic technical discussion is needed to gain a full understanding of Patchwork Interoperability, and in particular, of the potential problems that may crop up when one connects two different communication media together. This section provides an overview of the basic concepts. Section 3 describes all of the potential pitfalls and problems that prove that proper interoperability is anything but simple.

2.1 Radio-To-Radio Connections

The most basic and most frequently used cross-connection involves a pair of radio users, each on a different frequency or band, able to talk freely with each other through the use of an Interoperability Device. A simple block diagram for this type of communication is shown below.

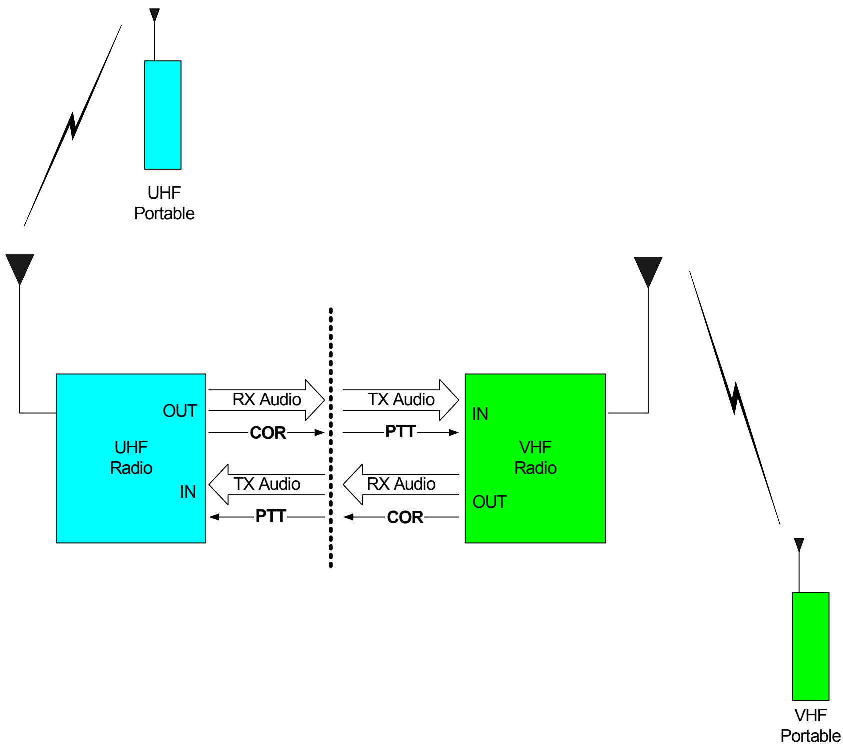

Figure 2-1 Radio-To-Radio

In Figure 2-1, a VHF radio and a UHF radio are cross-connected. This diagram would also hold true for an 800 MHz radio and an audio console, or any pair of four-wire devices.

As shown, the COR (Unsquelched Indication) output of one radio feeds the PTT input of the other radio, and vice versa. Similarly, the Receive Audio Output of each radio becomes the TX Audio Input of the other.

When the operator of the UHF portable keys up his radio, the COR output of the UHF radio of the cross-connected pair is activated, and this in turn activates the PTT of the VHF member of this cross-connected pair. The received signal is retransmitted on the VHF frequency to the VHF portable. When the VHF user replies, the reverse occurs.

A radio's **COR Output** becomes active whenever the receiver's squelch circuitry is detecting a valid signal, and RX Audio output is available throughout the time that the COR output is active.

When a **PTT Input** is active, a radio is put into the Transmit Mode (TX Mode), and its TX Audio input is transmitted as long as the PTT input stays active.

There are many radios that do not provide a COR output or any other unsquelched indication. An effective Interoperability System must be able to deal with this condition (as covered in Section 3.1). The diagrams that follow assume that, if this actual signal is not present, the system has some other effective means to identify the unsquelched condition.

2.2 Radio-To-Radio-To-Radio

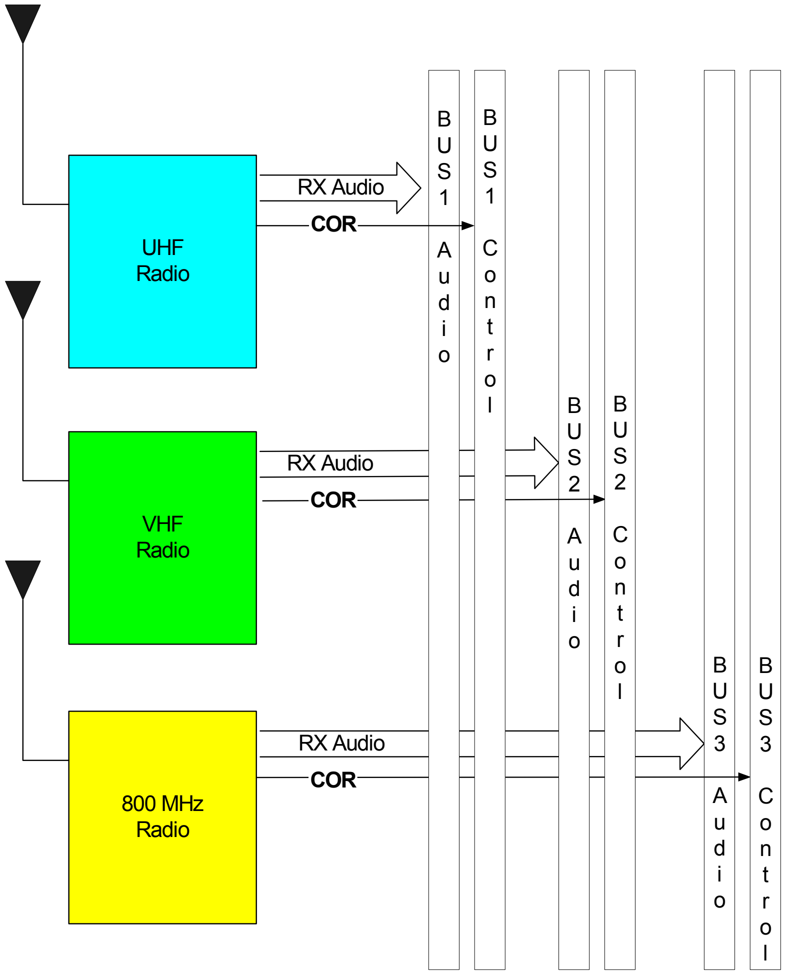

Figure 2-2 Multiple Radio Interoperability

The basic radio-to-radio interoperability concept can be expanded to include a large number of radios (certainly more than can actually carry on a coherent conversation), and the figure above shows how. Each radio has an Audio Bus that holds the received audio from that radio for retransmission by its cross-connected mates. Each radio's COR output is connected to that radio's assigned Control Bus.

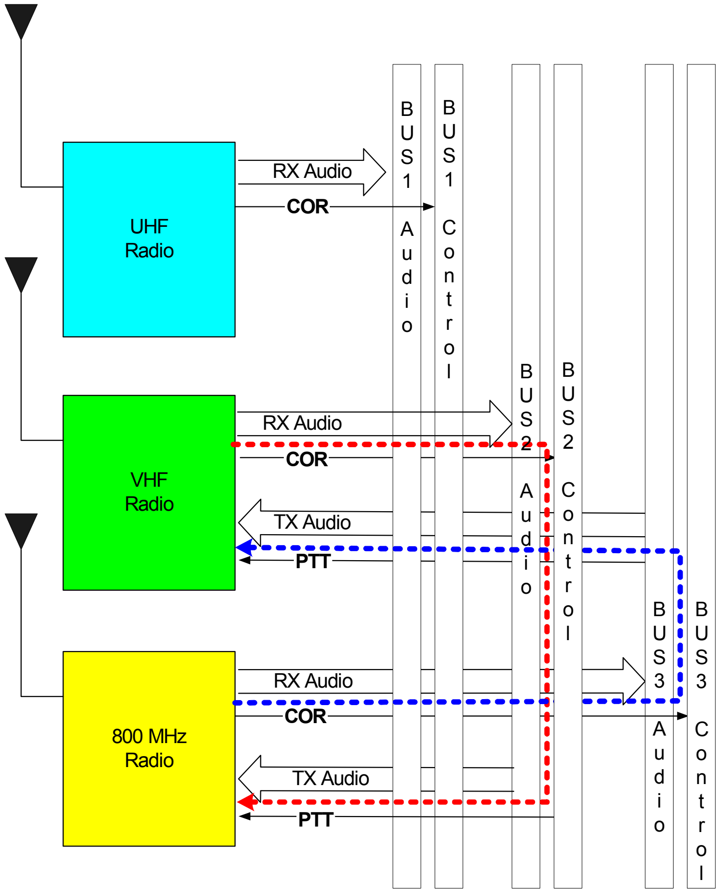

Figure 2-3 Sample Cross-Connection

In this figure, the VHF and 800 MHz radios are cross-connected. The RX Audio and COR connections don't change; all that is required is to connect the VHF Radio's TX Audio and PTT to the 800 MHz Radio's Audio & Control busses, and similarly the 800 MHz radio's TX Audio and PTT to the VHF radio's busses.

If all three radios were connected together, the RX audio and COR connections remain unchanged. The difference is in the TX audio and PTT inputs. Each radio's TX audio input would be connected to the RX Audio Bus of both of the other two radios. Likewise, each radio's PTT input would be connected to the Control Bus of the other two radios.

No figure is supplied because the previous illustration is already bordering on too complicated, and a diagram showing all of these connections would be even more complex, without enough colors to differentiate all of the paths. We won't even go there as this functionality is best handled electronically within an Interoperability Device.

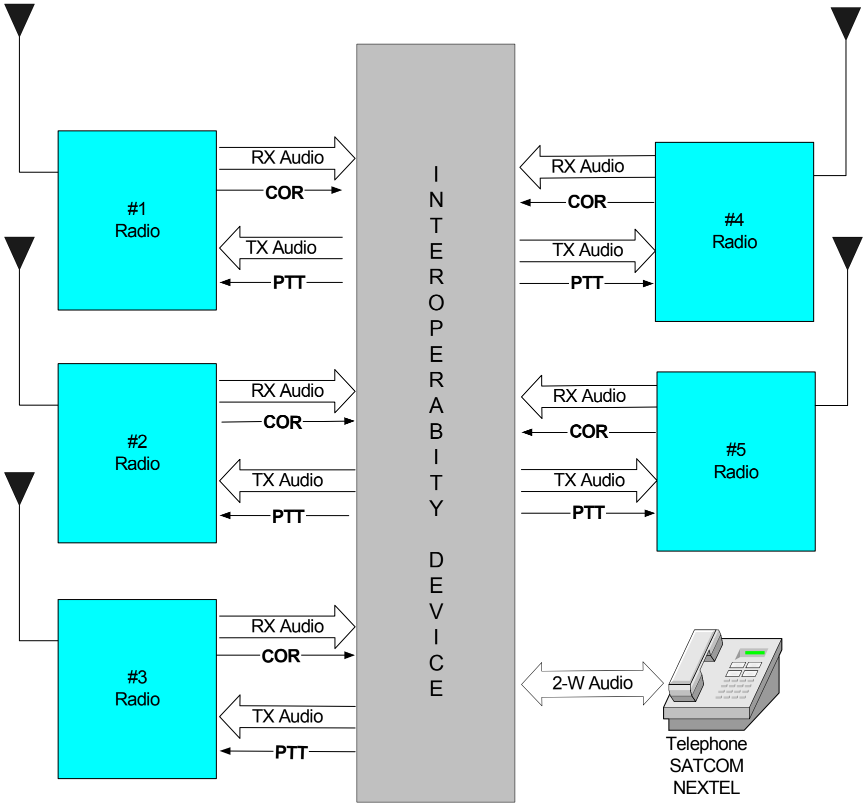

Figure 2-4 Basic Interoperability System

As you might expect, it takes more than a tangle of wires to create an effective Interoperability System. The main component is a box that takes the RX audio and COR signals from a group of radios as inputs, and provides them as outputs to cross-connected radios in the form of a PTT signal and TX audio. Mercifully, an understanding of the electronic circuitry within the Interoperability Device is not necessary.

Of course, the quality of the Interoperability System depends on what it does with these inputs besides spit them back out elsewhere as outputs. How it handles common difficulties and the extra features it provides, coupled with how easy it is to control and monitor, determine how capable the system is.

There are a number of potential problems that prove that creating a simple and graceful Patchwork Interoperability System is much more difficult than was illustrated in these basic diagrams. These complications are the subject of this handbook's next chapter.

Note that the Interoperability Device depicted in Figure 2-4 also interfaces a telephone system (or SATCOM, or NEXTEL phone). Telephone connectivity is explained in the following paragraph.

2.3 Radio-To-Telephone Connections

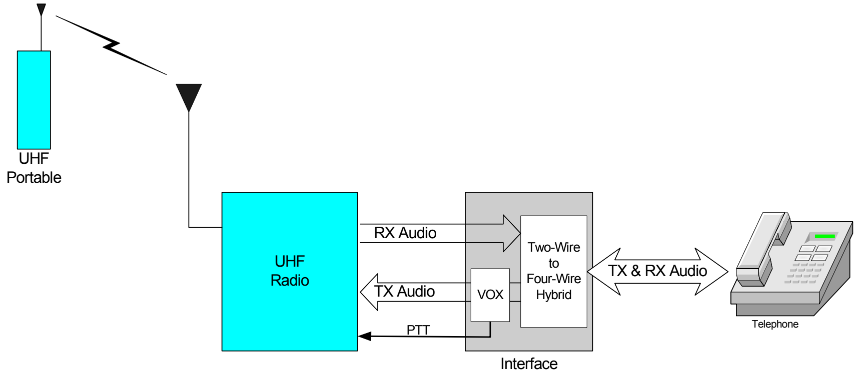

Figure 2-5 Radio-To-Telephone

The figure above shows a basic connection between a four-wire device (such as a radio) and a two-wire device (such as a telephone line). Two-wire devices carry audio in both directions, simultaneously, on a single pair of wires. An interface (commonly referred to as ***Phone Patch)*** is required between these two disparate media. In actuality, the phone patch two-wire connection does not interface directly to a telephone, but instead to the ***telephone system***. The phone patch would most likely be connected to a phone jack on the wall by a standard telephone cable with RJ-11 connectors on both ends. To talk over the radio via the phone patch, you would use your telephone to call the number associated with that phone jack on the wall.

With most standard two-wire devices (such as a telephone), there are no accompanying control signals such as PTT or COR. Because of its ability to carry both send & receive audio at the same time, these control signals do not benefit the telephone system. However, a two-wire to four-wire radio connection requires that a VOX function is provided to derive the COR signal from the incoming audio and supply the associated PTT output signal. The VOX (Voice Operated Xmit) triggers the PTT when a large enough signal is detected coming from the telephone system to indicate that the end-user is talking.

When connecting a telephone into an Interoperability System, the Phone Patch Interface Function shown can either be a separate piece of equipment or (preferably) this function can be contained within the Interoperability Device.

A **four-wire device** is one that has separate lines for transmit and receive audio signals. One pair for TX, and another for RX, totaling four wires.

A **two-wire device** carries both the transmit signal and the receive signal on the same pair of wires.

A **VOX** output is activated by the detection of audio that exceeds the set VOX threshold.

A **Phone Patch** interfaces the two-wire telephone system to a four-wire radio.

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3 Common Problems and their Solutions

So far, it seems pretty easy, just tie RX Audio to TX Audio, and COR to PTT… nothing to it. Like most things in life, once you get down to the detail level, it's not that simple (though there are Interoperability Devices on the market that are no more sophisticated than this). In this chapter we will examine a wide variety of potential problems. Don't worry, all of these problems have solutions and these solutions will be fully explained.

3.1 How To Know When To Transmit?

If a pair of radios are cross-connected, when one radio receives a valid signal and breaks squelch, its receive audio is transmitted by the other. Thus far, this has been explained by a simple connection of one radio's COR output to the other radio's (or the interconnect equipment's) PTT input. Unfortunately, many radios do not provide a COR output, and some radios can unsquelch randomly or inappropriately. The solution to these problem is to use either VOX or VMR, instead of the COR output, to signal when to transmit.

> A **VOX** function is triggered by the detection of an audio signal content above the set VOX threshold.
>
> A **VMR** function is triggered by the detection of audio containing elements of human speech. VMR is language independent and is unaffected by environmental sounds such as sirens or gunfire.

When a COR signal is not present, in most circumstances the best alternative is to use a VOX function. The VOX continuously monitors the receive audio, and if enough signal is available to indicate that the receiver is unsquelched, the VOX trips and sends an output to the cross-connected radio's PTT input. VMR is the best choice if the radio unsquelches randomly or inappropriately, or for radios that don't actually squelch (such as HF radios, which include "amateur" or "ham" radios). These problems will be discussed in subsequent paragraphs.

3.1.1 Important VOX Features

A dependable VOX function has three important features:

3.1.1.1 Variable VOX Threshold

A variable "total signal content" threshold allows the VOX to operate properly with a wide variety of radio models.

3.1.1.2 Receive Signal Delay

The VOX circuit takes a short period of time to detect the audio and trip its output signal (typically well under 100 milliseconds). If nothing is done to compensate, it's possible that part of the first syllable of an incoming message can be lost.

This is easily prevented by adding a small amount of delay (equal to or exceeding the VOX signal detection time) to the received audio signal before it is passed on to other radios for retransmission.

3.1.1.3 VOX Hang Time

Communications traffic would be very jerky if system transmitters unkeyed after every spoken word and had to re-enter the transmit mode for the next word. Since the VOX is only active when a preset audio level threshold is exceeded, it is inactive between words or during short pauses in speech.

This potential problem is also easily prevented. Some "hang time" should be added to the VOX detector output. The hang time keeps the VOX output active momentarily after an audio input is no longer detected. If more speech is coming, this holds the transmitter of a cross-connected radio until the speaker resumes talking. If no more speech is imminent, the VOX becomes inactive as soon as the short hang time is depleted. An adjustable hang time feature is preferred.

3.1.2 Important VMR Features

A dependable VMR Function has three important features (similar but not identical to the VOX function equivalents):

3.1.2.1 Variable VMR Threshold

The variable threshold allows the VMR to operate properly with a wide variety of radio models. The threshold is not related to the amount of signal present (as with VOX), but instead is based on how much human speech content must be detected before the VMR output is tripped.

3.1.2.2 Receive Signal Delay

Similar to VOX, a VMR function (a DSP algorithm) takes some time to detect the audio and trip its output signal. If nothing is done to compensate, the first syllable of an incoming message can be lost.

This is easily prevented by adding a small amount of delay (equal to or longer than the VMR signal detection time) to the received audio signal before it's passed on to other radios for retransmission. The VMR algorithm must consider a wide variety of signal characteristics before it can conclude that speech is present. Included is a search for rhythmic patterns that occur in speech. This extended measurement duration dictates that the VMR detect time (and the compensating audio delay) will be considerably longer than the VOX detect time.

3.1.2.3 VMR Hang Time

Communications traffic would be very jerky if system transmitters unkeyed after every spoken word and had to re-enter the transmit mode for the next word. Since the VMR is only active when the incoming audio displays components found only in human speech (and some portions of speech don't contain these markers), the VMR can be inactive during pauses or portions of words with non-specific content.

Again, this potential problem is easily prevented by adding some "hang time" to the VMR detector output. The hang time keeps the output active momentarily after human speech is no longer detected. If more speech is coming, this holds onto the transmitter of a cross-connected radio until the speaker resumes talking. If no more speech shows up, the VMR becomes inactive as soon as the short hang time is depleted.

3.2 Trunked System Channel Acquisition Delays

800 MHz Trunked Radio Systems (and other trunked systems) are a very common public safety communications format. When trunked system users begin a transmission, their radios must first communicate with the Trunking Controller. The Trunking Controller has ultimate control of each radio's TX function. When a trunked system radio PTT input is activated, the Trunking Controller first ensures that the user's radio is on an open channel, and then provides a tone to the user. This tone signals that it's now OK to begin speaking. This is an incomplete overview of Trunked Radio operation, but the concept essential to interoperability is the time gap between when a user activates a radio's PTT switch and when that user may begin speaking.

This gap poses a problem to the interoperability system. When the trunked system is cross-connected to another radio, the operator of the other radio does not hear the "Channel Ready" acknowledgement tone (also called the "go ahead" tone), and may not even be aware that he is cross-connected to a trunked system. ***If this radio operator simply begins talking, the first syllables or words will be lost while the trunked radio is silent and waiting to acquire a free channel.*** This is simply not acceptable in the circumstance when interoperability is most frequently needed- during a disaster or other unusual event when clear communication is crucial.

The solution is to add delay to the audio that's being patched from other radios into the trunked system. This trunked system's TX audio delay should match or exceed the channel acquisition time. This holds up the RX audio from cross-connected radios until the trunked radio is ready to begin transmitting. Relative to the Interoperability System of Figure 2-4, if radio #2 patches a trunked radio into the system, the TX audio from the system to radio #2 must be delayed.

Be sure to take into account the fact that channel acquisition times are increased when the Trunked System is exceptionally busy. Since any type of incident that requires interoperability is likely to be very busy for all communications, the Interoperability System must have the ability to add sufficient audio delay to compensate. It's important that the delay time be adjustable on-the-fly at the incident scene.

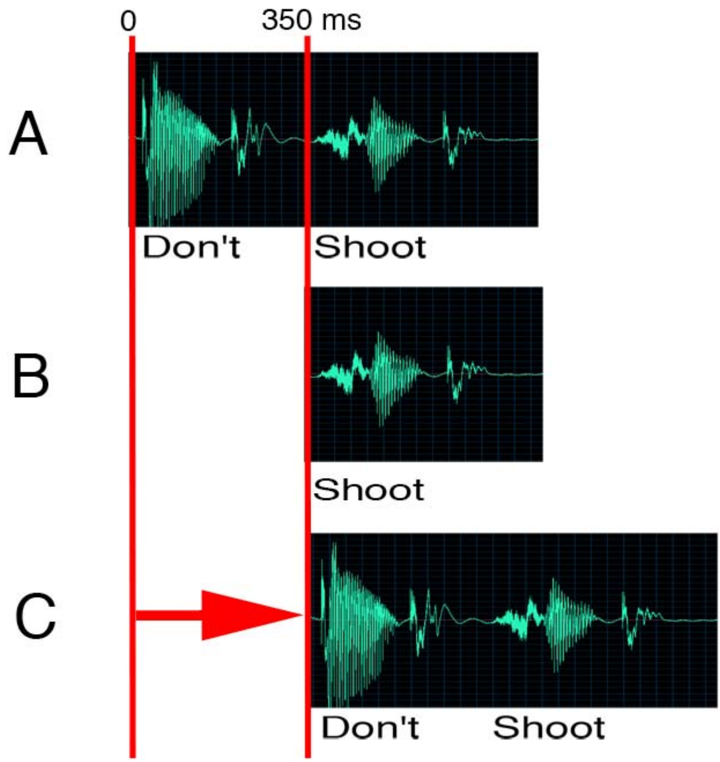

Figure 3-1 "Shoot" Versus "Don't Shoot"

A: The audio being sent into the Interoperability System by radio #1. Radio #1 is cross-connected to radio #2.

B: Radio #2 is an 800 MHz trunked radio with a Channel Acquisition Delay of 350 milliseconds. Therefore, radio #2 won't start transmitting the audio from radio #1 until 350 ms have past, and the first word of the message is clipped.

C: If the Interoperability System delays the audio to radio #2 by at least as long as the channel acquisition delay, the entire message gets through.

Figure 3-2 shows the potential communication problems that can occur when the necessary delay is not provided, with messages clipped or lost entirely.

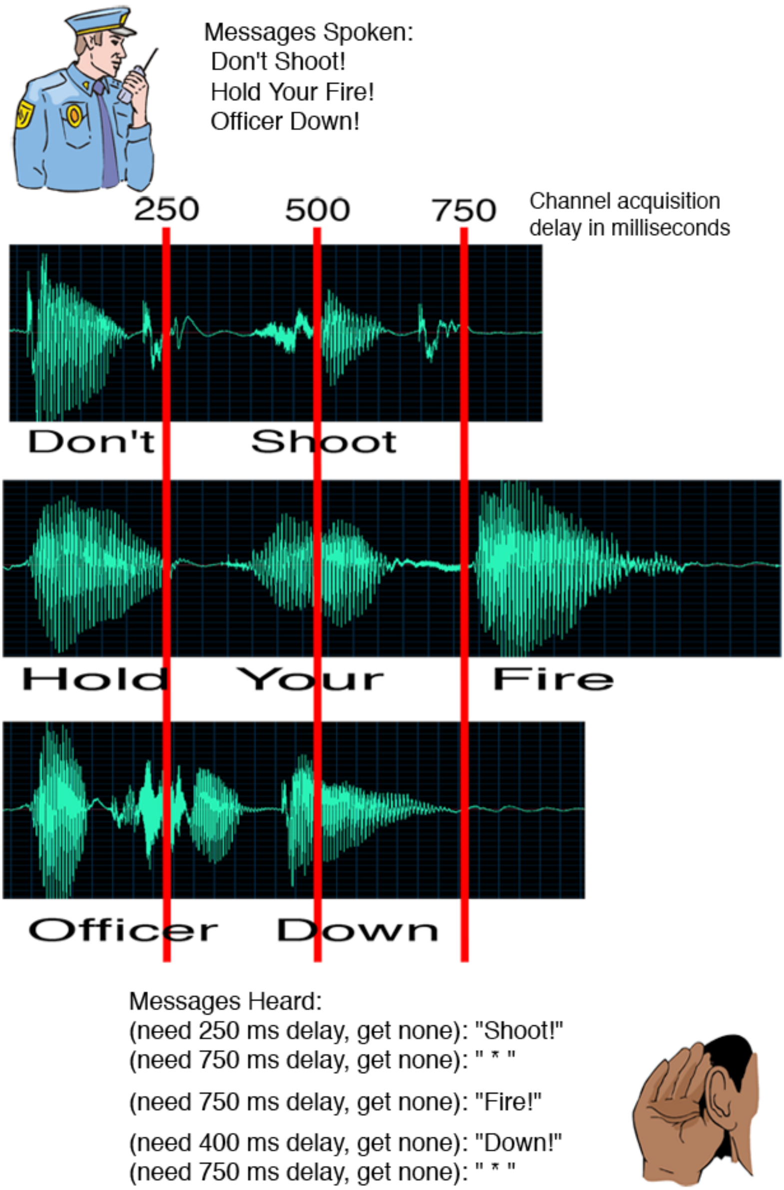

Figure 3-2 Why Audio Delay Is Crucial

3.3 "Ping-Pong" Effect

Some radios have a tendency to unsquelch momentarily at the end of each transmission. Remember that for any pair of cross-connected radios, whenever one radio is unsquelched, the other is keyed. If a radio in an Interoperability System exhibits the "momentary unsquelch" behavior, any cross-connected radio will momentarily (and inappropriately) transmit. If both radios unsquelch momentarily at the end of each transmission, the system will "ping-pong", with first one radio keyed momentarily and then the other.

This effect can be experienced when the PTT inputs are activated by either a COR input or a VOX circuit.

There are two ways to prevent this. The best is for the Interoperability Device to have an adjustable "Unsquelch Inhibit Timer After PTT". This function simply ignores any unsquelch detection (COR) that occurs immediately following the cessation of a transmit sequence. The length of the timer must be adjustable to optimize for different radios, which may exhibit the inappropriate unsquelch indication for durations as short as 100 milliseconds, and as long as several seconds.

Another way to prevent this is to use neither COR nor VOX, but instead use VMR. Since Voice Modulation Recognition will not trip unless human speech is actually present, these momentary (and inappropriate) unsquelch conditions will simply be ignored by the system.

3.4 Incompatible Volume Levels

When a conversation is taking place, especially a conference call between three or more people, clear communication is enhanced when all parties are heard at the same volume.

An Interoperability System should have an easy means to adjust the volumes to and from each of its radios or other communication systems. For optimal operation, these levels should be adjustable both during an initial setup and also on-the-fly to even out volumes during a conversation.

3.5 HF Retransmission Difficulties

The cross-connection of HF radio signals is problematic for two reasons:

- No COR output is provided
- The received audio is frequently very noisy

It's important to be able to interface HF radios into an Interoperability System because amateur radio operators (who use HF radios) are often very involved with disaster relief and emergency communications.

HF radios do not provide a COR output, and a VOX circuit can't be used because the noise inherent with HF receive audio output can cause the VOX to be tripped continuously. The Interoperability System must have a VMR function to gate the audio entering the system from the HF radio.

It is also very useful to have a DSP Noise Reduction Function to reduce the noise inherent in most HF receive audio signals.

3.6 False Keying Due To RFI

When a radio is installed in an environment with lots of RF emissions near the receiver's frequency, these emissions can cause the radio to unsquelch inappropriately. Some radios have a greater tendency for this problem than others. When this occurs, any radios cross-connected with the offending radio will momentarily transmit a loud burst of noise.

If any radio has a tendency to key on noise (and it's not possible to rectify by reducing the RFI or altering antenna placement), the best solution is to change that radio's system interface to VMR Mode rather than to use either COR or VOX. In VMR Mode, the Interoperability System will ignore these inappropriate noise bursts because the VMR will trip only when human speech is detected in the receive signal.

Any incident scene is likely to be a volatile RF environment because of the wide range of communications devices being deployed. This makes it very beneficial for the Interoperability System to allow an "on-the-fly" switchover to VMR mode when changing conditions warrant it.

3.7 Dispatcher Priority

If all Interoperability System users have equal priority, whoever transmits first is in control until this person ceases transmitting and gives someone else a chance. It may be beneficial and necessary to give priority to one or two important users.

This can be accomplished by being able to assign either TX Priority or Dispatcher Priority to all system interfaces.

Normally all interfaces are set to TX Priority. This means that if two or more radios or other four-wire devices (for example, a dispatch console) are cross-connected, whoever talks first is in control and no one else can be heard until this person stops talking (and releases the radio PTT).

If one user (for example, again consider a dispatch console), is set to Dispatcher Priority, an unsquelch condition received at the Interoperability System from this console will override the other user's control of the system. The dispatcher's audio will be transmitted instead (or will be mixed with the existing TX audio until this user unkeys).

The terminology makes more sense when one considers that the interoperability system consists of a group of radios connected to the main interoperability equipment. Refer to the following diagrams.

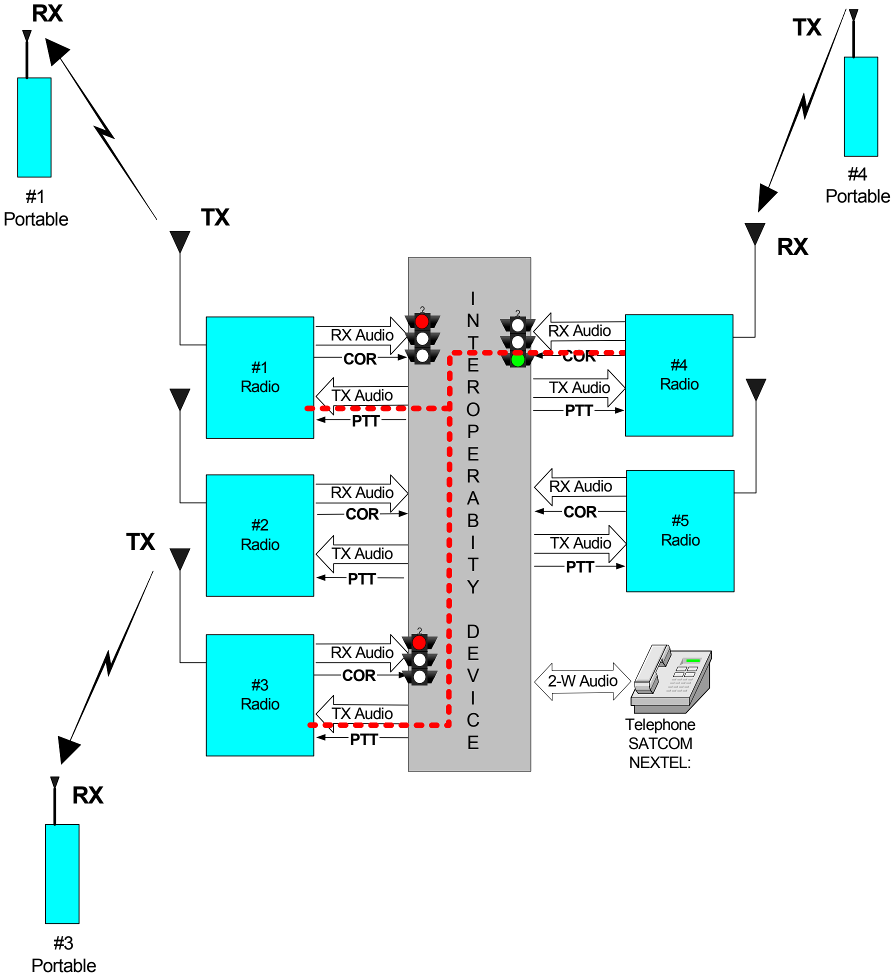

Figure 3-3 TX Priority

An interoperability cross-connection has been made to link radios #1, #3, and #4. At the moment depicted in Figure 3-3, a portable of the #4 radio system has keyed (TX) first, so its audio is being retransmitted to the #1 and #3 radio systems. The stoplights signify that, until the #4 portable unkeys, only the audio from the #4 radio will be allowed. If the #1 or #3 portables transmit before #4 stops transmitting, the associated active COR signals will be ignored by the system.

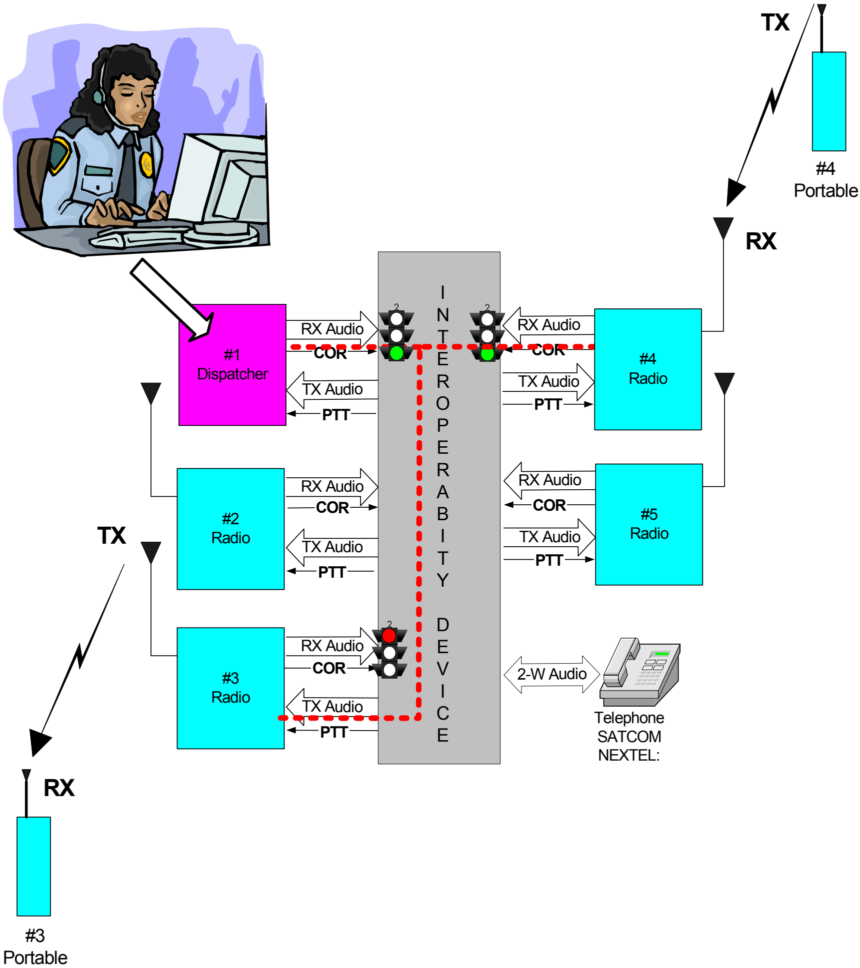

Figure 3-4 Dispatcher Priority

This figure shows a dispatch center interfaced to the #1 port of the sample Interoperability System. The #1 port has been configured for Dispatcher Priority, and an active COR signal at this port will not be blocked and will instead cause the dispatcher's audio to be retransmitted, even if the #4 portable stays in the TX mode.

3.8 "Stuck Channel" Syndrome

Consider again the basic concept of radio-to-radio cross-connections. When one radio is unsquelched, the other radios are transmitting.

Now consider what happens if a system radio is inappropriately unsquelched and stays unsquelched for an extended period. Possible causes are a problem with the radio, interference on its frequency, or a radio in the field that is stuck in the key-down mode, etc. It could simply be someone who is terribly long-winded and won't let the other system users break in. Whatever the reason, any system radios cross-connected to the problem radio will be stuck in the transmit mode, and the associated system users will not be able to access the Interoperability System. Refer to Figure 3-3 and consider what happens to the system if the #4 portable fails to unkey.

This problem is also referred to as "stuck mic".

The best solution is called "COR Sampling" (also referred to as "COR Sniffing"). With COR Sampling, the COR inputs of other radios in the connection will be occasionally sampled, and if one is active, it will be given control of the system. This provides an opportunity for another user to break in and take over the control of the system. This may give that user a chance to alert the system's operator that there is a problem (if there is an operator monitoring ongoing voice traffic), or if DTMF control is available, this user can disconnect his radio from the system.

An effective COR Sampling function should have the ability to set how long any channel is "Stuck" before the sampling begins. This is important because the "stuck channel'" radio must be cut off momentarily for the function to operate, and it's important that this does not happen inappropriately.

Another way to deal with a stuck channel is for a system operator to constantly monitor all system activity and disconnect any offending radios. In practice, this is too much to ask of a busy operator who most likely can only monitor each ongoing cross-connection for short time periods.

4 More Useful Features

The previous section listed likely problems and explained how to solve them. This section is a bit more optimistic; it explains some additional useful features of an Interoperability System that, if available, allow it to provide "better than adequate" performance.

4.1 Voice Prompts

Even with careful attention to training and practice, the unpredictable nature of disasters (or other events that require interoperability) make it inevitable that untrained persons will have to use the Patchwork Interoperability System. If the equipment includes automatic voice prompting, these users can be guided through the steps required for proper system operation.

When the Interoperability System includes the ability to cross-connect into Nextel, telephone, or SATCOM systems, even experienced users will be aided by voice prompting that helps them navigate the steps required to create a call.

4.2 Ability of System Operator to Monitor Ongoing Communications

Most Interoperability Systems have an operator (or group of operators) who monitor the status of the system via control software, and also use this software to create and dissolve cross-connections between the various radios, telephones, etc. that are interfaced to the system.

Also required is some means for the operator to know when changes in the cross-connections are desired. A simple and convenient way to do this is to give the operator the capability to monitor any or all of the interfaced systems. This requires a type of connection different from a standard cross-connection, as the monitor connection ties together only the RX audio, which is then sent to the system operator.

Also note that successful Interoperability Systems create cross-connections only as stipulated by a protocol agreed to by all parties. Refer to Section 9, which explains MOUs and SOPs.

4.3 On-The-Fly Optimization

It's extremely beneficial that system parameters, and particularly radio interface settings and options, can be adjusted as needed ***while the system is operational***. A few examples:

- One party of a conference call is a "quiet talker" who can barely be heard by the other participants. A quick increase of the RX Audio Input setting of this person's interface port resolves this problem.
- Due to unusually heavy communications traffic (or a number of other possible reasons) a trunked system's typical channel acquisition delay time grows longer and the Interoperability Systems TX Audio Delay setting is now not long enough to fully compensate. Additional audio delay brings it back in line.
- An officer is in some type of situation (too busy, injured himself, or perhaps attending to an injured person) and the officer must remain in contact through the Interoperability System but can't take the time to depress the radio PTT every time talking is required. With on-the-fly optimization, the system operator can switch the officer's radio interface unsquelched indicator from COR to VMR (refer to Section 3.1). The officer's radio can now be set to constant PTT, but will only access the system when the officer speaks.

Note that the control method (manual or by computer) dictates how the on-the-fly adjustments are performed.

4.4 DTMF Control

Many radios (and all telephones, Satellite phones, and Nextel handsets) have DTMF keypads. A resourceful Interoperability System can make use of this DTMF signaling capability, allowing it some control of the system. For example, a radio user (perhaps aided by the voice prompting mentioned above) can enter a DTMF sequence that requests a cross-connection to a another radio. For connections to a telephone, satellite phone or Nextel phone interfaced to the Interoperability System, the radio keypad can be used to enter the number to be called. The Interoperability System should also have the capability to automatically enter any special DTMF characters required by the satellite system.

DTMF can also be used as a security measure, whereby the Interoperability System requires the radio or telephone user (again, as directed by voice prompting) to enter a password. System access is denied unless the proper DTMF password is detected.

4.5 Noise Reduction

If a radio signal is noisy due to poor reception or any other reason, the retransmission of this noisy signal can be bothersome and tiring to all listeners, not to mention difficult to interpret. A DSP Noise Reduction Function can clean up the noisy signal before it is passed on to be retransmitted.

4.6 Stored Radio Interface Settings

There are a variety of adjustments that can be made to optimize a system interface port for best operation with any given radio. Most of these adjustments are identical for every radio of any particular model.

Instead of every individual system user being forced to determine the best settings, a user-friendly Interoperability System will have a stored library of optimal settings. The system should also have a means to quickly call up these settings (referenced by the radio model name) and apply them to an interface port whenever a radio is changed or added.

4.7 Audio Shaping

Pleasant sounding audio is less tiring to listen to and easier to understand. Some common radio model's RX audio sounds different than most others, largely related to frequency response characteristics. A capable Interoperability System allows these varying audio characteristics to be equalized by boosting or rolling off the high frequency response.

4.8 Ability To Interface Distant Radios

So far the discussion has assumed that if a radio is interfaced to the Interoperability System, it is directly connected by a cable. It is likely that not all of the radios that need to be interfaced to the system are located nearby, sot this direct connection may not be possible. There are at least two ways to create a remote connection:

- Via an IP-based network. Using the proper equipment at each end of the network, the IP-based network can act as a “cable extension”. See Section 8, “Radios are not Telephones” for an explanation of the special considerations that must be made.
- Via a Phone Patch. If the interoperability system has telephone connectivity, a phone patch (see Paragraph 2.3 Radio-To-Telephone Connections) can be used to bridge the gap. Be sure that the phone patch is a reliable automatic (non-manned) variety.

Figure 4-1 illustrates both types of remote interfaces. The #3 and #4 radios of the Interoperability Device first depicted in Figure 2-4 are now installed at remote locations. The #4 radio at the top of the figure is located anywhere that there is a digital network connection.

Note: When using a network to remotely interface a radio, be sure to use an IP (Internet Protocol) rather than some other network protocols or a proprietary one.

- IP is a widely accepted standard, and a well-known technology.
- IP networks can be build from inexpensive, readily available equipment supporting many different media types.
- IP is a "routable" protocol - data transmission can span multiple networks through the use of routers.
- IP has a well defined migration path for future growth and applications.

The #3 radio at the bottom of the figure is interfaced via the local telephone service. A keypad on the Interoperability Device dials the telephone number of the “phone patch” interfaced to the radio. Alternatively, the number is entered via the control software. For maximum utility, use a phone patch that has the ability to dial the phone number of the #3 port of the interoperability device, thereby allowing the connection to be initiated from either side of the telephone link.

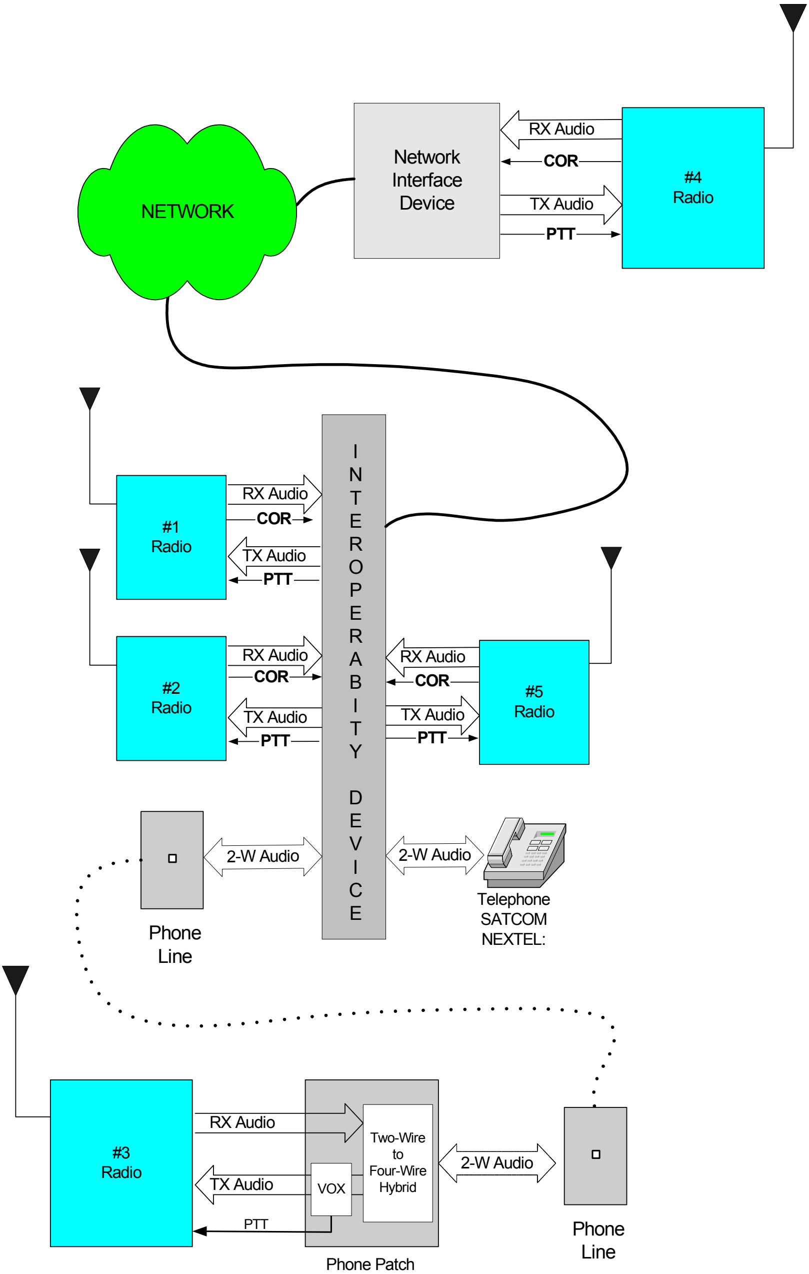

Figure 4-1 Remote Radio Interfaces

4.9 Enhanced Services from Commercial Carriers

When cellular handsets from a commercial carrier can be integrated into an Interoperability System, Public Safety personnel can take advantage of the commercial network's special features in addition to access to the system's existing private radio systems. With proper implementation, the Interoperability system users have the best of both worlds.

Some special features that commercial wireless carries can contribute include:

- Interconnected cellular communications, including voicemail, call waiting, call hold, call forwarding, and roaming.
- Text and numeric messaging and e-mail.
- Wireless data access.
- Java-enabled software for wireless handsets.
- Global Positioning System (GPS) tracking of handsets via satellites to locate individuals, track their movement, and assist the handset holder with navigation.
- Interoperability directories for network-based address books of telephone and radio contact information for public agencies and individuals across the country.
- Ruggedized cellular handsets that meet military specifications for dust, shock, moisture, and vibration at a much lower cost than traditional portable radios.

5 Applications

There are a variety of ways to implement an “Interoperability Solution”; each has aspects that are helpful (or essential) for one type of incident and potential drawbacks for another. In this section we will explore some implementation schemes, keeping focused on the types of incidents that drive the need for each application. The applications will be discussed from smallest to largest:

- Tactical/Portable
- Transportable
- Mobile (Vehicle Mount)
- Fixed Site
- Wide Area

As can be expected, there is a bit of overlap between these different applications. Some incidents are best served by a combination of Interoperability Systems implementations (especially with applications that are designed to work together). After the different types of applications are introduced, a discussion of overlap and the handoff of responsibility between applications will be presented. See Paragraph 5.6. Also provided are application examples; each of these examples provides all of the features and functions described in this handbook.

5.1 Tactical/Portable Applications

The defining characteristic of a Tactical Interoperability Solution is that it can be very quickly transported and deployed. It must be small enough to be hand-carried and set up in almost any location. In comparison, the mobile application is permanently mounted in a vehicle, and a transportable application includes the entire Interoperability System mounted in a transportable case, so it is considerably larger.

A typical incident that would require a Tactical Interoperability Solution is one that occurs unexpectedly in a remote location and requires quick coordination among the First Responders who are deployed to deal with the emergency. The Tactical Application can be easily carried to the scene by one of these First Responders and can also be deployed without the aid of any existing local infrastructure. Incident examples include:

- Major fire scene / Traffic accident / Other highway problem
- Hostage situation
- SWAT/Surveillance operation
- Hazardous waste spill
- Local weather related incidents (tornados, hail, flooding)
- Local evacuations

Important aspects of a Tactical Application include:

- Small size / light weight
- Rugged packaging (including weather proofing)
- Range of main power options, including AC, DC (+12V vehicle battery) and its own battery source
- Ability to quickly interface radios is essential
- Mobile phone or Nextel interface capability (connection to a telephone line not as likely to be needed for this application)

The basic concept of a Tactical Interoperability Implementation is that can be taken anywhere and be set up and running within minutes. This quick/flexible deployment concept requires that the Interoperability Equipment be small, lightweight, versatile, self-contained, and very easy to interface with whatever radios are in use in the area of deployment.

Putting all of this together, the optimal configuration is a carrying case that contains the following:

- The Interoperability Device
- Battery, AC power supply, and cabling to power from automobile +12 VDC source
- Cables to interface quickly to any radios likely to be used in the area of deployment (a “cable cache”), with quick-connect capability
- Ability to quickly optimize the Interoperability Device for best operation with any of these radios, including resolution of the potential problems noted in Section 3
- Ability to monitor and control the system manually, with computer control optional (but available)

Application Example:

The Raytheon JPS ACU-T applies tactical packaging to the well-proven ACU-1000 Intelligent Interconnect.

Quick connect/disconnect of radios and other devices is available via its side-panel connectors.

Control options include manual control (assisted by voice prompting, integrated handset and keypad, and an LED system-status display) or via computer control software.

Figure 5-1 Tactical Unit Example

The ACU-T is protected by its rugged foam-lined case.

The interface connectors, and control features (handset, keypad, speaker, and the LED matrix for quick review of connection status) are all exposed to allow quick deployment and operation.

The unit's battery is stowed beneath the foam and storage space is provided for cables and other equipment.

Figure 5-2 Tactical Case

5.2 Transportable Application

A Transportable Application is an entire interoperability solution in a transportable package. Obviously, with all system components (and radios) included, a Transportable Application will be larger than a tactical one. The transportable system may contain only a pair of radios or many more, so a wide variety of sizes are possible.

Important aspects of a Transportable System:

- Fully contained Interoperability System in a rugged case
- Easily accessible antenna ports, with long RF cables, so that antennas can be situated for minimal interference
- Light enough to be moved by no more than two people.

Helpful but not absolutely essential:

- Spare interface ports for at-the-scene system expansion and interface of additional radios (also called “walk-up ports”)
- Removable wheels (facilitates transport)
- Ability to be powered from either AC or DC source

The Transportable Application is best suited for these types of incidents:

- Long-term events such as political conventions or sporting events that take place over a number of days,
- Emergency interoperable communications during natural disasters such as tornados or hurricanes, related evacuations, as well as a short-term replacement for damaged infrastructure.
- Any other temporary radio installation for events that take place over a period of days or weeks.

> Note: The Transportable Application is suitable for use during the examples of incidents cited for the Tactical Application, particularly if no Tactical Application equipment is available.

Care must be taken in the design so that the failure of any individual component does not cause system failure. Beware of the use of a single power supply. Proper wiring techniques are also important so that the failure of any single wire has minimal impact on the overall system.

Application Example:

The Raytheon JPS TRP-1000 family provides complete Interoperability Systems in rugged transportable cases.

The version shown has dual cases for improved portability. The top case contains the ACU-1000 and two radios; this case can be used alone or with the lower case, which houses an additional 10 radios.

Pullout radio trays simplify configuration or replacement. Multiple power supplies (one per tray) remove single-points-of-failure thereby optimizing reliability.

Figure 5-3 Transportable Application

5.3 Mobile (Vehicle Mount) Application

The emergency situations that require interoperable communications don't give advance warning as to when or where they will occur. This is a major appeal of the Tactical and Transportable Interoperability Applications. These applications must be limited in size so they can be easily transported to the center of operations. If the Interoperability System is built into a mobile platform (a van, bus, trailer, etc.) a larger, more capable system is possible, and less setup is required when the Interoperability System arrives.

The core of the Mobile Interoperability System need not differ much from that of the Transportable System. The biggest difference is the increased capability to show up on the scene with a large variety of communications devices already interfaced to the system. If the mobile platform is a trailer, it can be dropped off at the scene while the towing vehicle is used to get supplies- for example generator fuel, food for the system operators, or anything else required to keep the system running.

Depending on the size of the vehicle, the Mobile Interoperability Application may contain any or all of the following:

- Multiple radio systems, completely interfaced and optimized.
- Telescoping Antenna Mast for improved reception and improved coverage.
- On board generator.
- UPS (Uninterruptible Power Supply) for any equipment that operates on the generator rather than vehicle +12 VDC.
- Satellite systems allowing field telephone communications to all agencies interfaced to the Interoperability System.
- Satellite system allowing in-the-field network connectivity.
- Pre-connected computer control equipment, including large touch screen monitors that facilitate system operation (but are more difficult to deploy with a tactical or transportable system).
- Personnel Tracking and Incident Management Systems.

These features make the Mobile Application ideal for incidents such as:

- Dignitary protection – as the motorcade travels, so does the interoperable communications system (particularly useful for movement across jurisdictional boundaries)

- Large-scale disasters such as forest fires – as the event moves, so does the command post. The Mobile Application can also be left on the site to temporarily replace damaged infrastructure.
- Movements of Chem/Bio matter or similar material.

The mobile application can also show up on the scene to take over after the Tactical or Transportable Applications have helped with initial emergency. Of course, if the Mobile Application is a van, it can remain functional while in transit, and will contain a very important asset: communications professionals and Incident Commanders.

Application Example:

Raytheon JPS mobile kits feature self-contained interoperability communications packages for integration into mobile platforms.

The MCK-1000 19” rack includes an ACU-1000 with six radios to cover UHF/VHF/800 MHz (and two spare “walk-up” ports for on-the-fly radio interfacing), “PD OnScene” patrolman tracking software, two wireless LANs (internal and/or external), a workstation to run this equipment and a server to connect and coordinate other computers within the system, along with an uninterruptible power supply to keep it all running in the event of power outages.

Figure 5-4 Mobile Application

5.4 Fixed Applications

Fixed applications are just that… installed in a fixed rack and not intended to be moved to the scene of an incident. A fixed application is the logical choice for a permanent Interoperability System installed at a communications/command center or radio site. It often makes sense to install the interoperability equipment either in the same location as the people who are going to control it or alongside the communications systems that it will interconnect. Fixed systems often allow better coverage and reception due to the ability to use higher power transmitters (when appropriate) and better/higher antenna installations.

Also consider locating the interoperability equipment at a remote radio tower site. This assures that the interoperability function will survive, even if a natural or man-made disaster separates that site from the rest of the communications infrastructure.

Fixed Applications are an excellent way to provide on-demand interoperability between existing fixed communications systems (for example, all of the systems within a single jurisdiction such as a county) or to deal wide-scale incidents or day-to-day interoperability requirements:

- Traffic accidents / Traffic pursuits
- Haz Mat response
- Fires or other local natural disasters
- Weather related incidents
- Evacuations
- Coordination of communications for any large gatherings such as sporting events, concerts, political rallies, etc.
- Coordination of communications between other Interoperability Applications (Wide Area Interoperability)

Fixed Applications can contain any or all of the features or capabilities of the Mobile Application. They often have the extra advantage of more space for equipment.

A fixed application can also be called a “Local Interoperability System”. When a number of Local Interoperability Systems are tied together via a digital network, they create a “Wide Area Interoperability System”, which is the next application type to be discussed.

Application Example:

Figure 5-5   Fixed Application

The field-proven Raytheon JPS ACU-1000 is the heart of a fixed installation. An ACU-1000 chassis can hold up to 12 interface modules; and a pair of chassis can be connected together to bring this up to 24. Each of these modules create an Interoperability System interface to:

- 4-wire devices (such as radios and audio consoles, or Nextel handsets)
- 2-wire devices (such as telephone systems, satellite phones, and cellular phone systems)
- Ethernet IP-based networks

The ACU-1000 Control Processor Module coordinates the system, and can receive commands either by manual control (via the unit's front panel keypad) or remotely via RS-232 or over an IP-based network.

The ACU-1000 radio interface modules contain all of the optimization features described in this handbook. Also available are interface cables and quick-optimization templates for over 100 commonly used radio models, as well as for numerous Nextel handsets, cellular phones and satellite phones.

Application Example:

The ACU-1000 is the basic interoperability device of the Metropolitan Interoperability Radio System (MIRS) of the Alexandria Virginia Police Department, with 22 primary public safety agencies participating.

This system was originally designed and implemented by the National Institute of Justice AGILE Program.

This Interoperability System uses a dual-chassis ACU-1000 to provide radio to radio and radio to telephones cross-connections.

Case study and installation information available at www.agileprogram.org

Figure 5-6 Host Site, MIRS Program

Computer Control Application Example:

The ACU-Controller provides an intuitive Graphical User Interface for easy control of an ACU-1000 or ACU-T, whether in a Tactical, Mobile, or Fixed Application version. The main screen, shown in Figure 5-7, provides a clear overview of current system status.

Cross-connections are made and dissolved by a simple point-and-click procedure. Other features include the ability to store specific system configurations for later recall, a log file of system activity, and the ability for both local and remote (via an IP-based network) control.

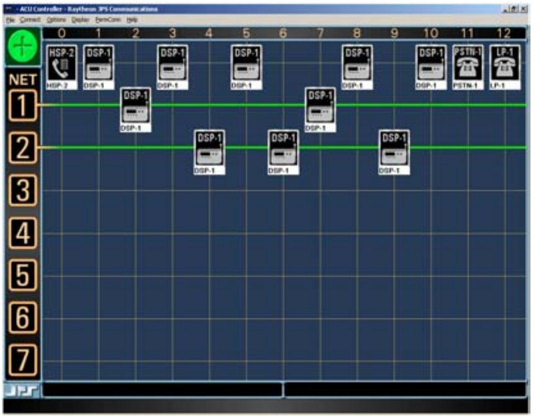

Figure 5-7 GUI Control Software

The ACU Controller Interface Settings Screens (one for each port) allow quick and easy adjustments of all of the interface setup and optimization parameters discussed in this Handbook. Optimization of a radio interfaced to an ACU-1000 or ACU-T is simplified further by the availability of stored radio templates. These radio templates allow instant application of any of the program's extensive library of setups for commonly used radio models.

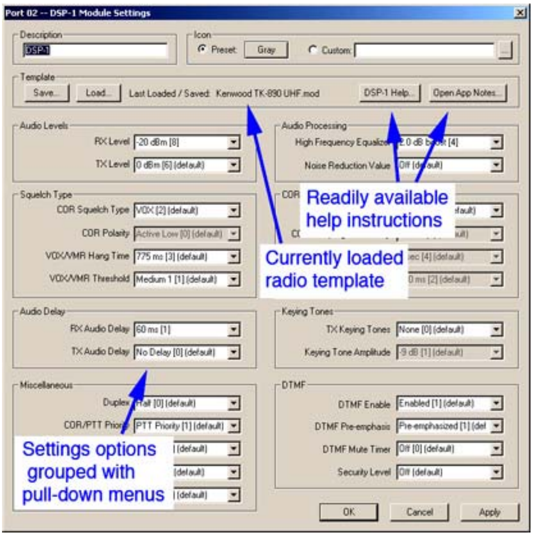

Figure 5-8 Interface Settings Screen

5.5 Wide Area Applications

As the name suggests, Wide Area Applications cover a large geographical region (for example a “statewide system”). When the principles of Patchwork Interoperability are followed (that is - interconnecting existing communications systems, rather than replacing them), the Wide Area Application consists of a number of Fixed, Tactical or Mobile Application Systems tied together via an IP based network. This network could be the Internet, but is more likely a LAN or WAN (Local Area Network or Wide Area Network).

A well-designed overall Wide Area Interoperability plan should include the ability to bring any Mobile or Transportable Applications into the Wide Area System on an as-needed basis.

A Wide Area Application has obvious uses for incidents that take place over a large area (for example, tracking a suspect car as it traverses the state) or to provide access to distant assets at a local emergency (tying in distant medical experts to assist at an accident site).

Application Example:

The Raytheon JPS WAIS Controller GUI Software is specifically designed to provide comprehensive network control of Wide Area Interoperability systems.

A variety of screens can be called up to view the status of local operations as well of the complete Wide Area System.

Figure 5-9 Wide Area Application S/W

5.6 Coordination Between Applications

The optimum overall Patchwork Interoperability System will contain aspects of each of the different applications, with each performing tasks that they are most suited for, and some overlap occurring as responsibilities are handed off between the applications.

For example, consider the surveillance/chase of a suspected criminal vehicle:

The Wide Area Application is made up of a number of Fixed Site Applications, and the operators of the Wide Area System may begin the operation, controlling interoperability communications handoff between a number of Fixed Systems as the vehicle repeatedly crosses jurisdictional boundaries. The operators keep ahead of the situation, informing jurisdictions in the projected path of the vehicle.

At each Fixed Site Application, communications are coordinated between any local professionals who are involved (or may be called on to be involved) with the incident. These communications can be controlled either at each Fixed Site, or by the Wide Area System operators.

If the incident turns into a multi-vehicle crash scene coupled with an “on-foot” chase operation, the initial First Responder to arrive equipped with a compact Tactical Application can quickly deploy an interoperability network at the scene. Since the Tactical System is designed for speed and flexibility it can be quickly configured to allow coordination between the other professionals who soon arrive, such as EMS, firefighters, hazardous material experts, and law enforcement personnel (local and/or federal). The Tactical system should also allow interoperability between these local personnel and the Incident Commander manning the Fixed Application.

If some expert advice is available at the other end of the state, a request can be passed up through the system and the expert patched in using the Wide Area Application.

If the situation warrants, the Incident Commander can also dispatch a Transportable or Mobile Application. A Transportable System or a fully equipped van or trailer brings additional on-site communications capability. If needed, the van or trailer can provide a mobile command post at the scene or be used for more long-term communications. Once the immediate emergency has ended, these applications allow the Fixed and Wide Area Systems to stand ready for another emergency event (once they have sent an “all clear” to everyone involved).

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6 Scalability

One of the main tenets of Patchwork Interoperability is that it ***connects existing communications systems together, and does not replace them***. This concept should be carried further, in that the Interoperability System should be designed in such a way that increased coverage and functionality can be added to the initial portions of the system without the need for wholesale replacement of the initial system.

Here are some of the ways that this can be done, starting from the smallest system component and building upward:

- The basic interoperability equipment should be modular in design, so that additional modules can be added, thereby allowing additional communications systems to become part of the initial Interoperability System.
- The basic Interoperability System should also be capable of expansion by the ability to connect multiple units of the basic interoperability equipment together. This can be done either by simply cabling the basic units together or by creating a simple, inexpensive Local Area Network (LAN) to make the connections.
- These basic "Local Interoperability Systems" should furthermore have the capability to be connected together over an IP Network. This can be the Internet, but more likely will be a WAN or LAN operated by the group or agency that runs the Interoperability System. Wireless Ethernet Networks (Wifi) can also be used. When the systems are connected together, they create a Wide Area Interoperability System (WAIS).

Local Interoperability System (LIS): A system that allows interoperability between members of a group of communications systems that are collocated.

Wide Area Interoperability System (WAIS): A WAIS System ties together a number of LIS systems, typically via an IP-based network (the Internet or a LAN or WAN).

6.1 Scalability of Training

An aspect of scalability that's easy to overlook in the early system design stages (but would be glaringly obvious later) is that a system upgrade must not obsolete all of the training that went into the initial system. A serious effort to provide interoperability requires much training and much practice, which is time consuming and expensive. A well-designed Interoperability System's family of applications shares many characteristics and therefore the training for any one applies to all.

When computer control programs are used (mandatory for all but the smallest system), the basic concepts and actions used for the smaller systems must remain applicable to the control software of larger systems

6.2 Scalability by Leveraging Commercial Networks

Public safety users often rely upon commercial wireless services using cellular phones and Push to Talk (PTT) service. Capability to cross-connect Interoperability System users into these commercial networks provides an access point into a single national system, and to all of the Public safety users of that system. Nextel Communications, for example, has developed solutions specifically for the Public Safety sector, and now has nearly one million public safety subscribers and 12.9 million subscribers nationwide.

This leveraging of commercial networks can entail any or all of the following:

- Adding an agency that uses cellular handsets with Push-to-Talk capability to the interoperability system, so that this agency's personnel can now communicate with the other members of the system as well as each other.
- Tying in cellular handsets with Push-to-Talk capability, thereby including all other Public Safety personnel that have handsets with similar capability.
- Ordering new commercial carrier accounts and tying their Push-to-Talk numbers and/or talkgroups into private radio systems.
- Emergency deployments of commercial carrier handsets and/or cell site capacity. Simply put, it's easier to provide cellular-type handsets and related training to a group of people who arrive at an incident seen without communications than it is to provide radios and related training. For example, the DC Area Sniper Task Force deployed 600 Push-to-Talk units, five base stations,

and one cell site on wheels to provided interoperable communications among ten Federal, state, and local public safety agencies.

If interoperable communications are expanded through the use of commercial service providers, these providers should offer the following cellular features to meet the needs of Public Safety agencies:

- Priority queuing of Public Safety users' Push-to-Talk signals.
- Although cellular networks are unencrypted, the carrier should offer digitally modulated voice signals for over-the-air security.
- Push-to-Talk functionality (Nationwide preferred).
- Multi-party talkgroup dispatching.

Other useful features include Talk group scanning capabilities and emergency prioritization of group call dispatches.

6.3 Scalability of Control

There are a variety of ways that an Interoperability System can be controlled, some are more appropriate to small systems and some work best with a large Wide Area system. These control systems must also be scalable; this means that if one control system does not work for both big and small systems, an operator must be able to migrate from the smaller control system to the larger with minimal difficulty.

There are bound to be new operations required in order to control the expanded functionality, but the operational steps required for the control of smaller (local) systems must give the operator an intuitive sense for performing similar steps with larger (wide area) systems.

Possible control methods, from smaller systems to larger, include:

- Automatic control. If a radio is interfaced to the Interoperability Equipment, it is constantly cross-connected to every other radio that is also interfaced. This is not a very useful control method for obvious reasons.
- Manual control. A local operator determines which of the system's radios are interfaced together by means of switches or a keypad on the main Interoperability Unit. This method should also include a means for the operator to monitor the interfaced radios so that requests to make or break connections can be heard and heeded.

- User Control. Radio or Telephone users control their access to the system via their DTMF keypads. This method becomes ever more problematic as the system grows because there is no way for any of the users to know the total system status. The failure of some users to properly break cross-connections that they had previously put together can also tie up the system.
- Local computer control. A computer connected directly to the Interoperability Equipment allows an operator to view and modify the system's interconnection status. Well-designed GUI interfaces that enable this functionality and also provide a means to optimize system parameters are essential features of any computer control software.
- Remote computer control of single local system over an IP network. Similar to local computer control, but the operator can be located anywhere on the network.
- Multiple remote computer control of multiple local systems. The use of an IP network provides the possibility for any number of operators to control any number of individual systems.
- Wide area computer control over a network. Control software that is specifically designed to show the status and control the multiple local systems that are interconnected together to create a wide area system. Note that even a simple creation of a cross-connection between two radios, each interfaced to a different Local Interoperability System, requires simultaneous control of both of these local systems.

Local computer control is usually the best control method for tactical, transportable or vehicle-mounted systems. There must also be a means for the operator to know when system users desire to be connected or disconnected from other users. The capability to monitor ongoing system communications is the simplest way to achieve this.

Manual control is adequate for small tactical systems as long as the operator has a convenient means to visually monitor system connectivity status and can also listen to ongoing communications, so that users can indicate when they need operator intervention.

Fixed systems should have the ability of remote computer control, as the best location for installing radios and other RF equipment is where the Interoperability Equipment is likely to be installed, but this is usually not the best place for a dispatcher.

Wide Area Interoperability Systems require software made specifically to control them.

7 Limitations

This section tells what a Patchwork Interoperability System can't do, what its limitations are and what undesirable effects it may have on any existing communications systems.

7.1 Not a Magic Bullet

The paragraph heading could also have been "garbage in <> garbage out". The Interoperability System can ameliorate some of the shortcomings of the communications systems that are interfaced to it, but it can't eliminate them. Usually the best that can be done is for the system to handle these shortcomings gracefully (see Section 3 for a discussion of common problems and potential solutions).

In particular:

- Garbled, indecipherable audio from a faulty link into the system will result in garbled, indecipherable audio being cross-connected to other system users.
- The Interoperability System can't extend the coverage of existing radio networks.
- The system can't remove Trunked Radio System Channel Acquisition Delays.

7.2 Training Deficiencies Can Compromise The System

Simply put, if an emergency or other unexpected incident occurs, and interoperability between a number of agencies is suddenly required, smooth system operation is not likely to occur unless adequate training and practice has occurred beforehand. It's important to work through any kinks in the system and discover any training problems ahead of time so that remedial action can take place before a real emergency occurs.

Note that the incidents when interoperability will be most needed are emergencies where effective communications can help calm a chaotic situation. This type of situation is not the place for on-the-job-training.

7.3 The System Can't Do More Than Its MOU & SOP Will Allow

The Memorandum of Understanding is a legal agreement between all system users, stating what actions can be taken, and the Standard Operating Procedures stipulate how the actions are performed. See Section 9 for a complete explanation of each.

The importance of these documents can't be overstated. If not carefully crafted, activities may be allowed that cause more harm than good. On the other hand, if the documents are written in an overly specific manner, they may prevent unanticipated but necessary action.

7.4 The Interoperability System Can't Win Turf Battles

If some participating agencies do not share the common vision, and maintain internal policies and attitudes that are contrary to the spirit of interoperability, everyone else's work may come to naught.

8 Radios are not Telephones

This section introduces the concepts related to the use of the Internet or other network as a telephone, and explains why these standard VoIP practices aren't sufficient for radio interoperability over a network.

8.1 VoIP Overview

In recent years providers of telephone service and equipment have promoted VoIP to send telephony (speech) signals over the Internet. After being converted to a digital format, the telephony signals can be treated like any other data.

> **VoIP**, or *Voice over Internet Protocol*, provides a method of converting voice to a digital format that can be sent over the Internet (or any data network using the Internet Protocol) without the need for traditional telephone lines from a phone company.

For many companies the attraction of VoIP lies in the potential cost savings; if traditional telephony services can be provided over the data network, the charges related to building and maintaining a separate telephone network can be eliminated. In most cases this works well. VoIP telephones are dropping in price, and VoIP services are available from numerous providers. Voice quality is good; indeed, many customers cannot tell the difference between a VoIP telephone call and a traditional analog call.

However, VoIP places special requirements on the data network and the underlying equipment. While this usually doesn't cause major problems for simple "telephone-like" communications, the same isn't true for radio communications. To understand why, let's first examine some characteristics of traditional (analog) telephones and telephone service:

- Telephones require a *full duplex* connection, which means that both parties must be able to talk and be heard at any time, even at the same time. Telephones also provide *sidetone*, which feeds a small amount of the mouthpiece audio back into the earpiece, so you hear yourself talk through the phone. Sidetone does two things: it lets you know the phone circuit is "live" and also subconsciously helps you to regulate how loud to speak.

- Telephones send their mouthpiece audio and receive their earpiece audio over a single pair of wires. In other words, the transmitted and received signals are superimposed on the same set of wires.
- Finally, analog telephone calls are placed over a *circuit-switched* network. This means that when a telephone call is made, a *dedicated circuit* is set up for it and devoted solely to this one call for the entire duration of the call. The characteristics of this circuit are known and predictable.

A different model is used in the IP networking world. On an IP network the data is broken up into *packets* – small, manageable chunks of data that can be quickly transmitted over the network. Packets from many different devices or applications can be routed over the same network at the same time. This is called *packet-switching*, and allows the same path to be shared by many users simultaneously. This efficient use of resources is one of the main advantages packet switching has over circuit switching.

This versatility and efficiency saves money but incurs a different cost. Since the amount of data being sent over the network varies, so does the time it takes to deliver the data. When traffic is heavy, in order to transfer all of the packets from multiple sources the network equipment may have to delay the delivery of the packets. This delay varies relative to the amount of network traffic, and is impossible to precisely predict. With computer data this delay does not cause much of a problem (the computer doesn't mind waiting), but in VoIP applications the delay can be noticeable and sometimes objectionable. Designers of telephony VoIP equipment go to great lengths in the VoIP software to deal with delay problems, but ultimately the performance of a VoIP telephone system depends upon the network being used. Too much delay, or too much variation in the delay (also called *jitter*) can cause unacceptable performance and poor voice quality.

Full-Duplex: All parties of a conversation can speak and be heard at the same time.

Half Duplex or Simplex: Only one person can speak (and be heard) at a time.

8.2 VoIP Vs. RoIP

What does this have to do with the use of VoIP in the radio world? Extending radio communications over an IP network brings a different set of requirements, and requires a different type of VoIP solution. Radio is traditionally *half-duplex*, which means that only one party talks at a time. The user is responsible for controlling the radio, and uses the radio's *Push-to-Talk* (PTT) switch to place the radio into the transmit mode. Reception of a radio transmission is indicated by a signal from the radio called *Carrier Operated Relay* (COR).

In order to fully extend radio communications over an IP network the PTT and COR signals must be supported by the network equipment, and Telephony VoIP equipment has no provisions to do so. The Radio-over-IP (RoIP) solution designed by Raytheon JPS Communications does support them, and makes the linking of radio equipment across an IP network a simple task. The JPS RoIP solution also provides additional compensation for network delay and jitter, allowing its use on networks that would not properly support telephony VoIP equipment.

> **RoIP**™, or *Radio over Internet Protocol*, not only converts voice to a digital format that can be sent over the Internet or other IP-based network, but also converts the PTT and COR signals that are essential for seamless radio interoperability. Also included are extra delay and jitter compensation.

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9 MOUs and SOPs

Successful Interoperability System implementations should include both a “Memorandum of Understanding” (MOU) and a “Standard Operating Procedure” (SOP).

> An **MOU** is a legal agreement between systems users allowing all parties in the system to cross-connect their radios and other specified communications systems together.
>
> An **SOP** stipulates the protocols and procedures for all interoperability cross-connections.

There is no strict border between an MOU and the accompanying SOP. Frequently some of the operating procedures are included in the MOU; sometimes there is no SOP and the MOU encompasses the features of both. Occasionally the MOU is one short page and all of the rest is outlined in the SOP.

The procedural mechanisms that make interoperability work are not “one size fits all”. The MOU and SOP vary depending on the Interoperability System equipment implementation, geographical boundaries, the current combination of state, local and federal regulations, and most important, the system’s stated purpose. However, many have one thing in common- the most persistent roadblocks encountered are resistance to change and existing internal policies, procedures, and attitudes that run counter to a shared vision of mutual gain through effective interoperable communications.

9.1 Memorandum Of Understanding (MOU)

An MOU is an agreement between all of the agencies that operate the communications systems that are interfaced to the Interoperability System (for example the County Sheriff’s Office, the Metro Transit Police Department, or a city EMS Department).

The MOU states that each of these agencies agree that under the stipulated circumstances, and following a set procedure, defined elements of their communications system may be cross-connected to the other communications systems that are party to the agreement. The “stipulated circumstances”, “set procedure”, and “defined elements” are described in detail in the Standard Operating Procedure. Some or all of these elements of the SOP may also be included in the MOU.

MOUs may also outline agreements between agencies to share or swap radios, or may define maintenance agreements.

The MOU is a legal document signed by all of the agencies that are participating in the Interoperability System, and should also define the procedures whereby any of the signatories may withdraw from the MOU.

9.2 Standard Operating Procedures (SOP)

An SOP clearly defines all aspects of the Interoperability System's operation, including:

- What communications assets may be interfaced with the Interoperability System (frequencies, trunking talk groups, etc.)
- How to request that a cross-connection be made or broken.
- Who is authorized to direct that a cross-connection be made or broken, and who is authorized to operate the equipment to create or break a cross-connection.
- What types of incidents or events trigger the use of the Interoperability System.
- What procedure must be followed to implement the cross-connection (what types of notification are required under different circumstances, what type of approval is required and by whom, etc.)
- Specific operational protocols and procedures that describe in detail what must be done and what can't be done, e.g.:
    - Use plain English; no "10-codes" (such as "10-4") or other jargon or slang is allowed. Some dramatic illustrations- in many places "10-1" means "signal unreadable", while in Chicago it means "Police Officer needs help".
    - How agencies identify themselves during cross-connected communications.
- What procedures will be followed to regularly test the Interoperability System
- Procedures to modify the system (based on test results or other reasons).

10 Other References

These web pages contain further information that is helpful in gaining a full understanding of Interoperability Systems and identify some grant opportunities.

10.1 Patchwork Interoperability Handbook

This link leads to a PDF version of this handbook for free download.

www.jps.com/patchwork

10.2 MIRS/AGILE System

A Wide Are Interoperability System was sponsored by the National Law Enforcement and Corrections Technology Center - Northeast (NLECTC-NE) Prince George County Police and Fire Departments. It's called the Metropolitan Interoperability Radio System (MIRS)/AGILE and is centered in Alexandria, VA.

www.agileprogram.org/research_dev/voice_comm.html

10.3 Handbook from the US DOJ

This link is to a document produced by the Department of Justice's Office of Domestic Preparedness (ODP) entitled, "Developing Multi-Agency Interoperable Communications Systems: User's Handbook Applicable To: ACU-1000 Modular Interface/Interconnect System and TRP-1000 Transportable Radio Interconnect System"

www.ojp.usdoj.gov/odp/docs/acu_trp1000.pdf

10.4 Maryland Statewide System

Information regarding the statewide system can be found at:

www.jps.com/index.asp?node=73&item=131

10.5 Grant Opportunities

The FY2004 Assistance to Firefighter Grant information can be found at:

http://www.usfa.fema.gov/

The purpose of this grant is to provide one-year grants directly to Fire Departments of a State to enhance their abilities with respect to fire and fire related hazards. This program has been funded each year since FY2002 and a bill has been introduced to fund it through FY2007. It is presently funded at $750M.

The FY2004 ODP Homeland Security Grant Program can be found at:

http://www.ojp.usdoj.gov/

These grants are passed through and administered by each state. This grant program has three (3) grant programs consolidated into it. Their purpose is to provide planning, equipment, training, exercise, and management and administrative funding to emergency prevention, preparedness, and response personnel in all 50 states, the District of Columbia, the Commonwealth of Puerto Rico, and U.S. Territories, while expanding the scope and reach of the program. The following Programs have been brought under this one Grant heading, the "State Homeland Security Program" funded at $1.685B, the "Law Enforcement Terrorism Prevention Program" funded at $500M and the "Citizen Corps Program" funded at $35M.

The FY2004 Urban Areas Security Initiative Grant Program (UASI) can be found at:

http://www.ojp.usdoj.gov/

This Grant Program has two (2) grant Programs consolidated into it.

One is funding for Mass Transit Authorities to enhance their security and improve their preparedness. Mass Transit is funded at $50M.

The second program provides funding for Urban Areas and was designed to address the unique security needs of high-threat, high-density urban areas. Specific Cities and Urban areas around the country are specifically identified for funding in this program. This program is funded at $675M.

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