OVER-THE-AIR SOFTWARE DOWNLOAD CONSIDERATIONS FOR PUBLIC SAFETY AND OTHER MARKETS

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ABSTRACT

Over-the-air (OTA) software download procedures can enable reduced communications system lifecycle costs, more easily updated features, and improved interoperability to markets such as public safety, the National Aeronautics and Space Administration (NASA), and commercial organizations by quickly and efficiently allowing update of the operating characteristics of software defined radios (SDR). Standardizing these procedures may provide further benefit in many markets.

This paper reviews the potential benefits and implementation issues of OTA programmable (OTAP) radios. It describes how overall lifecycle costs might be reduced through both lower operational costs and a potentially longer operational life. This paper also presents the necessary steps for ensuring that OTAP radios take full advantage of more easily updated features. It also discusses an overall solution for improving interoperability, an issue that has gained attention particularly within public safety agencies. It delineates some of the issues with OTA software downloads, including the components and memory that typically must be added to the radio, spectrum that is required for OTA transmission, and the actual download procedures. Included in this discussion are risk mitigation procedures and mechanisms to reduce these issues.

Subsequently, the paper examines the conditions under which it might be beneficial to standardize the software download procedures. It also discusses the merits of specific download standardization procedures, including whether certain download parameters should be mandated or optional.

1. INTRODUCTION

SDR technology holds great promise for the public safety community. It also offers great potential for other entities such as NASA and commercial providers. However, this paper focuses on public safety primarily because of the attention that public safety communications has received. Many of the benefits of SDR technology are further enhanced by OTA software downloads. However, a number of issues must first be resolved in order to fully realize these benefits. This paper discusses the potential benefits of OTA software downloads, issues and potential resolutions, and the role standards could play in the development of this technology.

Currently, updated parameters or a new version of software are downloaded to a radio via a hard connection, such as a programming cable; only one radio can be programmed at a time. Figure 1 illustrates the current method of downloading new software onto a radio.

Figure 1: Current Software Download Method

Use of OTA downloads allows broadcast of updated parameters or a new version of software to the recipient radios. Because the transfer is done remotely, multiple radios can receive the transmission at the same time. However, because this download is completed remotely, a technician may not be present at the receiving end to troubleshoot any problems that arise. This leads to some of the issues discussed in Section 3. Figure 2 illustrates the OTA software download method of transmitting new software.

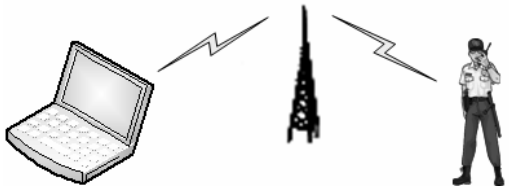

Figure 2: OTA Software Download

Four types of OTA software downloads can be used—

- Changing parameters—Small transmissions that only adjust parameters and do not affect the actual software.
- Software patches—Small transmissions that correct errors in the code. These types of transmissions are performed on an emergency basis.

- Over-the-air re-keying (OTAR)—Transmissions that install new security keys on the radio. These transmissions are typically only used by federal public safety agencies because of the cost.
- Adding features or upgrading software—Large transmissions that add or replace large pieces of software. These transmissions are typically planned well in advance.

Because OTAR standards are already being addressed by other standards bodies, this paper focuses on the other three types of downloads, although the content is also applicable to OTAR downloads.

2. BENEFITS

OTA software downloads provide numerous benefits for the public safety community. Most of these benefits are inherent in SDR technology, but are enhanced by OTA software downloads. Two of the key benefits are increased public safety interoperability and a reduction in radio lifecycle costs.

2.1. Interoperability

The SAFECOM Program states that interoperability "refers to the ability of critical emergency response systems or products to work with other systems or products without special effort on the part of the user." Currently, public safety radio systems operate in several bands. In order for public safety agencies to communicate across systems and bands, a number of solutions relying on additional hardware, dispatcher intervention, or additional spectral resources have been developed.

These interoperability solutions can be grouped into four major categories—swapping of radios, audio switches, network-based solutions, and mutual-aid channels. Swapping of radios refers to the procedure of giving a host system radio to the incoming first responders. The incoming responders then use both radios to communicate. Audio switches use hardware or software to transmit and receive data over a number of radio channels. Network-based solutions, such as console patches, are typically used with trunked radio systems to connect talk groups via a dispatcher. Mutual-aid channels are radio channels dedicated for interoperability use only. Table 1 describes circumstances when each type of system is typically used and some of the issues surrounding its implementation.

OTA software downloads can provide seamless interoperability without relying on any additional equipment or spectral assets. By using OTA software downloads, arriving first responders can download the interoperability parameters and immediately gain access to the host radio system.

Table 1: Current Interoperability Solutions

Solution	Situation	Issues
Swap radios	• Small number of new responders • Disparate radio systems	• Requires the use of two radios • Limited by the number of available extra radios • Has a high cost of maintaining radio cache
Audio switch	• Disparate radio systems • Systems have overlapping coverage footprints	• Is spectrally inefficient • Has a limited number of ports on a switch • Adds cost of purchasing switch
Network-based solution	• Pre-established physical connections between systems • Users are within coverage of their home system	• Requires advanced coordination • May require dispatcher intervention • May limit the number of links between systems
Mutual-aid channel	• Radios operate in the same frequency band • None of the above interoperability solutions are readily available	• Only works when all radios are capable of operating in the same frequency band • Only useful for command and control because of limited capacity

For example, today, arriving first responders must begin by determining the type of interoperability solution that will be used. This information is often passed to them by their dispatcher. Depending on the type of solution being used, the steps needed to establish interoperability vary. If a network-based solution or mutual-aid channel is being used, the dispatcher may be able to help the arriving first responders establish interoperability while en route to the scene. Should the incident response be using an audio switch or radio swapping for interoperability, the arriving first responders must wait until they arrive at the incident scene to establish interoperability. Once they have arrived, they would be required to see the incident commander to either pick up radios or loan one of their own radios for the audio switch. In these cases, the arriving first responders

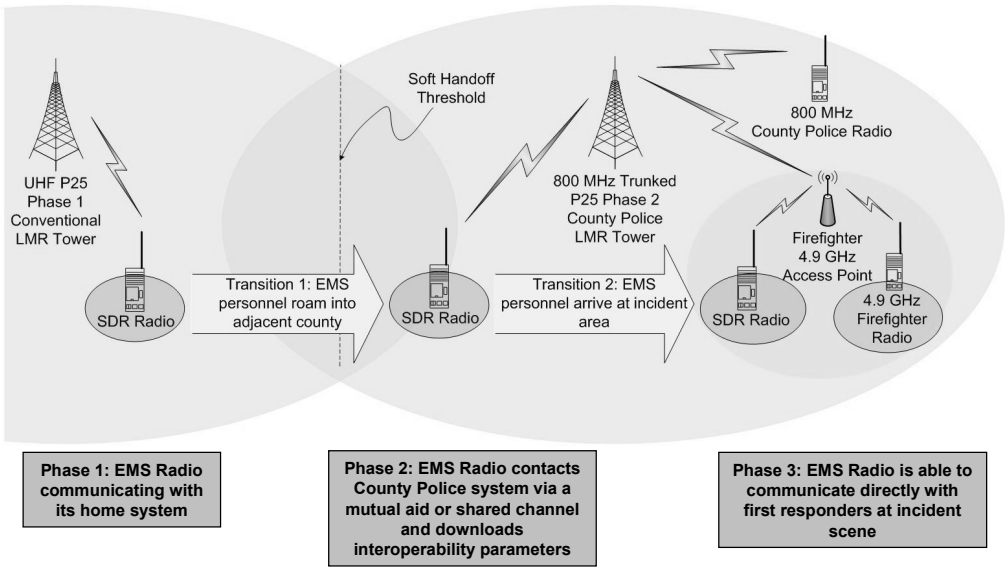

Figure 3: Interoperability Using OTA Software Downloads

must spend valuable time attempting to establish communications.

On the other hand, OTA software downloads have the potential to enable establishment of interoperability before arrival at the incident scene and without dispatcher intervention. The arriving first responders could receive the interoperability parameters via OTA software downloads either from their home system or when they arrive within coverage of the incident scene's network. Once these parameters were downloaded, the arriving first responders would have full communications with the incident command staff. This could allow for coordination and planning before the new responders even arrived at the incident scene. In addition, it would not rely on a dispatcher to provide information or establish connectivity. This process is shown in Figure 3.

Remote software downloads also can establish interoperability with non-traditional first responders. As recently demonstrated by the response to Hurricanes Katrina and Rita, traditional public safety first responders are not the only responders at an incident scene. National Guard and non-profit organizations such as the Red Cross are critical responders to large-scale incidents. OTA software downloads have the potential to easily and efficiently include these responders on the same radio system as public safety agencies. This new coordination could help improve communications and the overall incident response.

2.2. Lifecycle Costs

The cost of building and maintaining a radio system can weigh heavily on public safety officials. Because most public safety radio systems are funded by taxes, officials often are required to be frugal. However, although the initial implementation cost of OTA software downloads might be more expensive, these costs could be quickly recovered by savings on operations and upgrade costs.

One potential lifecycle savings would be that remote software downloads might help reduce the cost of fixing radio problems. Routine software maintenance, such as software patches, could be accomplished while the radios were still in the field. This would have a few benefits. First, it would reduce the amount of time to complete the maintenance because all of the radios could be patched at once. Secondly, because the radio technician would not need to physically touch each radio, it could save technician time. Finally, fewer spare radios might be required. Currently, users often drop off their radios for maintenance and use spare radios for the duration. If most software maintenance procedures could be performed via OTA software downloads, the demand for spare radios could be lowered. In turn, the agency may need to maintain fewer spare radios.

At times, there may be a need for the system to revert to an older software version. Examples of this situation include reverting to the original programming when returning from a mutual-aid response or if problems are detected with an upgraded software version. In these situations, either a user override or an OTA override could be used to instruct the radio regarding which software version to use. Without OTA software downloads, each

radio might need to be brought into the radio shop for servicing.

Remote software downloads also have the potential to greatly reduce the cost of upgrading a system. These upgrades could simply be adding a few features or upgrading to a new version of software. Using OTA software downloads for upgrades offers many of the same benefits as for software maintenance. Radio technicians would not need to physically touch each radio to perform the upgrade. This would save technician time and reduces some of the upgrade costs. Additionally, a large cache of loaner radios is not required because the current radios do not need to be removed from service to perform the upgrade. Finally, because all of the radios can be upgraded at once, upgrade is faster.

3. ISSUES AND POTENTIAL RESOLUTIONS

Although OTA software downloads have many potential benefits, several issues must first be addressed. Since this paper only addresses OTA software downloads, it is assumed that the radios can upload the new air interface personalities and guarantee that the properties specified by the regulatory bodies are preserved [1]. Some of these OTA software download issues require a technical solution while others can be resolved via operational changes. Two major issues are interrupted downloads and airtime requirements.

3.1. Interrupted Downloads

One major issue facing OTA software downloads is ensuring a complete and usable transmission is received by the radio and that the new software operates correctly. Currently, a radio technician can physically check to ensure that a new software download has been correctly transmitted from the laptop and is operational before returning the radio to the field. However, because OTA software downloads occur without a technician present, the radio must be able to diagnose a problem with the download and revert to its previous programming automatically.

Interruptions come from many sources, including radio frequency (RF) interference, radio transmission, or radio failure. Some of these, such as use of the radio during download, could be minimized by appropriate timing of the download. Others, like radio crashes and unexpected interference, cannot be anticipated or avoided. Therefore, the radio must be able to handle incomplete downloads.

The first step in ensuring that there is always one complete piece of working software is to add redundancy. This could either mean housing two complete sets of code on the same storage device or maintaining redundant storage devices. Depending on the device configuration, redundant storage devices requires installing two memory modules in the radio. Using redundant storage devices is the more reliable method because it can eliminate any interrupted downloads caused by flaws in the storage media.

Adding redundant memory should not add significant cost, weight, or power requirements to the radio, particularly if only parameters and patches are downloaded. Storage devices, especially flash memory, are used in numerous consumer electronics. An example of this is the Apple iPod Shuffle, which is a low cost, flash memory device. This type of memory could very easily be used in SDR radio construction.

In practice, a version of the current, working software would be installed in two memory areas. When an OTA software download was sent, this version would be installed in only one of the memory areas. This would help ensure that an operational version of the software was always available in the radio. Additionally, the redundant storage devices could allow a radio to continue to operate in the event of a failure of one of the devices.

When using OTA software downloads, the radio must also be able to perform completeness and operability checks of the new software and revert to the previous programming if necessary. Immediately following an OTA software download, a "self-check" should first verify that the download was satisfactorily completed. A wide variety of error-checking algorithms can be used for this purpose.

3.2. Airtime Requirement

Depending on the type of OTA software download, there is the potential to strain the radio system by transmitting a large amount of data at one time. Small downloads, such as interoperability parameters and software patches, have a much lower potential for causing airtime constraint issues. However, large downloads, such as system upgrades, have the potential to overwhelm the radio system. Therefore, the airtime requirements of OTA software downloads must be addressed.

There are numerous strategies to reduce the strain of downloads on the radio system. These include—

- Transmission packetization
- Off-peak transmissions
- Use of a single channel for transmissions.

Each of these solutions has its own advantages and disadvantages, which are discussed below.

The first option to reduce the airtime requirements would be to split larger downloads into smaller, identifiable pieces and complete the download via installments. This method, similar to the packetization of Internet traffic, would reduce the load on the system by reducing the amount of data sent during each transmission. While the number of transmissions would increase, the size of each transmission would be more manageable. This option is extremely attractive, if not required, for large downloads such as system upgrades. Additionally, because the main purpose of

a public safety communications system is to protect life and property, the ability to interrupt downloads is paramount. Packetizing the data would allow users to transmit when required without being required to start the entire download process over again.

To further enhance the efficiency of this method, a reliable transport layer could be added on top of a broadcast data stream. Transmission Control Protocol (TCP) is an example of this implementation. Under this method, a packet header identifies each packet as a specific component of the transmission. Once the entire data transmission has been sent, each radio responds with the identification information of the packets it did not receive. The system then only needs to resend the missing packets. This verification procedure to identify the missing packets could reduce the number of required transmissions.

The second solution for reducing the strain of large downloads would be to send the transmissions at off-peak times. Historically, public safety agencies can determine when their system has the lowest load. These are the times that the system has the most excess capacity and can therefore be used to send the OTA software downloads. There are a few disadvantages to this method. The biggest issues are that the radio must be turned on and in coverage during these off-peak times. Additionally, different types of public safety agencies, such as law enforcement, fire, and emergency medical services, have varying system usage patterns. If the system is shared among multiple agencies, it might be extremely difficult to identify an appropriate time for the transmission. Further, an unexpected event might occur during the scheduled transmission time, requiring more resources than initially expected. Thus, this solution is usually best for augmenting other solutions and not replacing them.

Another option would be to designate a single channel for OTA software downloads. By using only a single channel, the amount of system resources devoted to the download would be limited. Additionally, by using only one channel, the download process could be more easily automated. This method limits the confusion regarding where to tune the radio to receive the download.

Designating a single channel for OTA software downloads also has potential to enhance interoperability benefits. When responders from outside radio systems were dispatched, they could be given instructions by the dispatcher on when to tune to the download channel. This would enable them to receive the download while in transit, simplifying the download procedure. Because this download would need to occur during an emergency response, simplicity is strongly preferred.

A national interoperability channel would further enhance this option. This channel could be used by all public safety agencies for the transmission of OTA software downloads of interoperability parameters. By using the same channel nationwide, the process of downloading new parameters would be even simpler. Because all agencies would use the same channel, incoming responders would know exactly which channel to tune their radios to in order to receive the download. This would reduce the likelihood of incorrect or limited information being passed to the responders by dispatchers.

4. STANDARDS

As more manufacturers implement OTA software downloads, standardization could be beneficial. This standardization has the potential to increase efficiency of transmissions. Additionally, creating standards for OTA software downloads could decrease the amount of training required for radio technicians.

Standardization is most critical for the transmission of interoperability parameters. Interoperability is one of the key benefits of OTA software downloads, and simplifying the process of downloading these parameters is important. It becomes even more important when public safety agencies responding to the same incident have radio systems built by different manufacturers.

At a major incident response, such as an airplane crash, numerous local, state, and federal public safety agencies would be required to respond. Because a large number of agencies would be responding, it is easy to assume that different radio manufacturers would be represented at the scene. If there was no standardized method for transmitting interoperability parameters, in the best case, several OTA software downloads would be required to update all of the radios to the proper interoperability parameters.

More realistically, several problems would most likely exist at the scene. First, the host system might not have the software required to download the properties for all of the radios. Purchasing the software for other systems might be an investment that not all public safety agencies could afford. This could delay or prevent OTA software downloads of the interoperability parameters.

If the host system had the required software to transmit interoperability parameters to multiple manufacturers, there is no guarantee that the radio technician would have been trained to operate the various software packages. Because the technicians only work with their system's software, training on additional software packages might be seen as an unnecessary expense. Even if the technicians were trained, they would be inherently more familiar with their own software package. Under the high-stress atmosphere of a major incident response, radio technicians might not effectively or efficiently run the download software for other radio manufacturers. Standardizing the transmission of interoperability parameters would simplify and increase the efficiency of OTA software downloads for interoperability.

In these types of incident responses, time might mean lives or property damage.

One key to the success of the standardization of interoperability parameter transmissions is the involvement of radio manufacturers and software developers. They are the major players in designing and implementing OTA software download protocols, and their insight is extremely valuable. Additionally, they have the knowledge to streamline the interoperability parameter transmission template and point out potential pitfalls. Once a standardized template has been developed, it should be formalized by a standards body such as TIA. This would help ensure that the template would be available to all software developers.

5. CONCLUSION

OTA software downloads have great potential to enhance interoperability and reduce lifecycle costs in the public safety community. As coordination increases among public safety agencies, the need for interoperable communications grows. Additionally, maintenance and upgrade costs could be greatly reduced through the use of OTA software downloads. By implementing these software changes over the air, radio technicians would no longer be required to physically touch each radio, thereby reducing the implementation cost. Additionally, the maintenance and upgrades could be completed faster because all of the radios could receive the transmission at once.

In order for these benefits to be realized, several next steps need to be taken. First, the public safety community should gain a better understanding of the benefits and best implementation practices of OTA software downloads. Efforts are already underway by organizations such as the SDR Forum and the Public Safety Special Interest Group to inform the public safety community. The benefits and implementation best practices should be taken into account when procuring new public safety radio systems.

Additionally, public safety agencies should join forces with the vendor community to define the necessary standards. The role of each community is critical to ensuring that the standards are practical and can be implemented. These standards can help reduce the cost of implementing OTA software downloads while still realizing the interoperability benefits.

Finally, public safety agencies, in coordination with the Federal Communications Commission and regional planning committees, should focus their efforts on allocating nationwide channels that could be used for the download of interoperability parameters. Although interoperability benefits can be realized without such a channel, the simplicity of using this type of channel can further enhance the benefits.

6. REFERENCES

[1] J. Mitola, “Software Radio Architecture: A Mathematical Perspective,” *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 4, pp. 514–538, April 1999.

Over-the-Air Software Download Considerations for Public Safety and Other Markets

Presented to the SDR Forum

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Mark Jones

Booz Allen Hamilton

- Introduction and Technology Overview
- Benefits
- Issues and Potential Resolutions
- Conclusions and Next Steps

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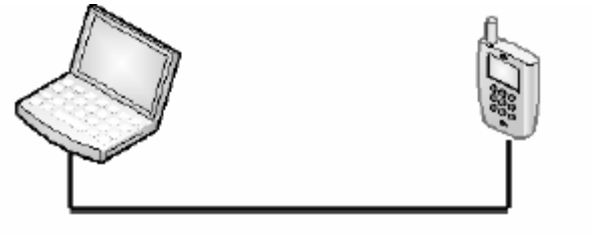
Over-the-air (OTA) software downloads will provide many benefits, but still have unresolved issues

- OTA software downloads hold great promise for the public safety community
- Many of SDR technology benefits can be further enhanced these downloads. The two major potential benefits are—
  - Interoperability
  - Reduced lifecycle costs
- However, a number of issues must first be resolved to fully realize these benefits. Three key issues are—
  - Interrupted downloads
  - Airtime requirements
  - Roaming/interoperability simplicity
- Several next steps are required to help maximize the potential benefits of OTA software downloads

NOTE: Although public safety examples are used in this paper, the concepts are is also applicable to other markets

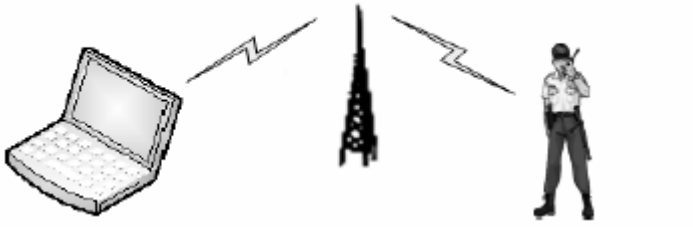
OTA software downloads use different technology to transmit programming information

Current Technology



- Requires use of a cable to transfer programming information
- Can only program a single radio at a time
- Requires that a radio technician be present

Over-the-Air Software Downloads



- Uses existing infrastructure to broadcast programming information
- Can program a single radio or all radios on the system at one time
- Does not require a radio technician to physically touch each radio

There are four major types of OTA software downloads

- **Changing parameters**—Small transmissions that only adjust parameters and do not affect the actual software
- **Software patches**—Small transmissions that correct errors in the code
- **Over-the-air rekeying (OTAR)**—Small transmissions that install new security keys on the radio
  - These transmissions are often only used by federal public safety agencies because of the cost of secure radios
- **Adding features or upgrading software**—Transmissions that add or replace large pieces of software
  - These transmissions are typically planned well in advance

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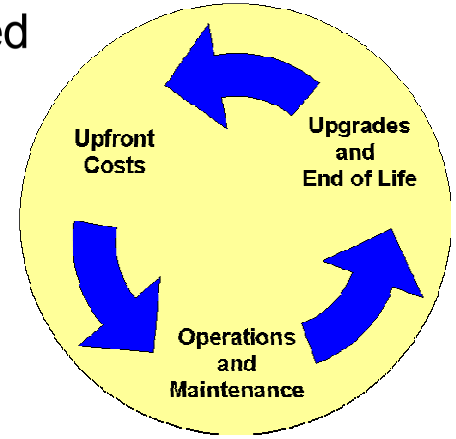
The two major benefits are seamless interoperability and decreased lifecycle costs

- Interoperability is defined by the SAFECOM Program as "the ability of critical emergency response systems or products to work with other systems or products without special effort on the part of the user"
  - Public safety radio systems operate in several bands
  - A number of interoperability solutions rely on additional hardware, dispatcher intervention, or additional spectral resources have been developed
  - OTA software downloads can provide seamless interoperability
- Lifecycle costs can be defined as all costs associated with setting up, operating, and upgrading the radio system
  - Upfront costs refer to the initial costs to purchase and install the system
  - Operational and maintenance costs recur on an annual basis and can vary based on the age of the system
  - Upgrades enable an existing radio system to be brought closer to the current level of technology. These upgrades can either improve productivity or extend the life of the system



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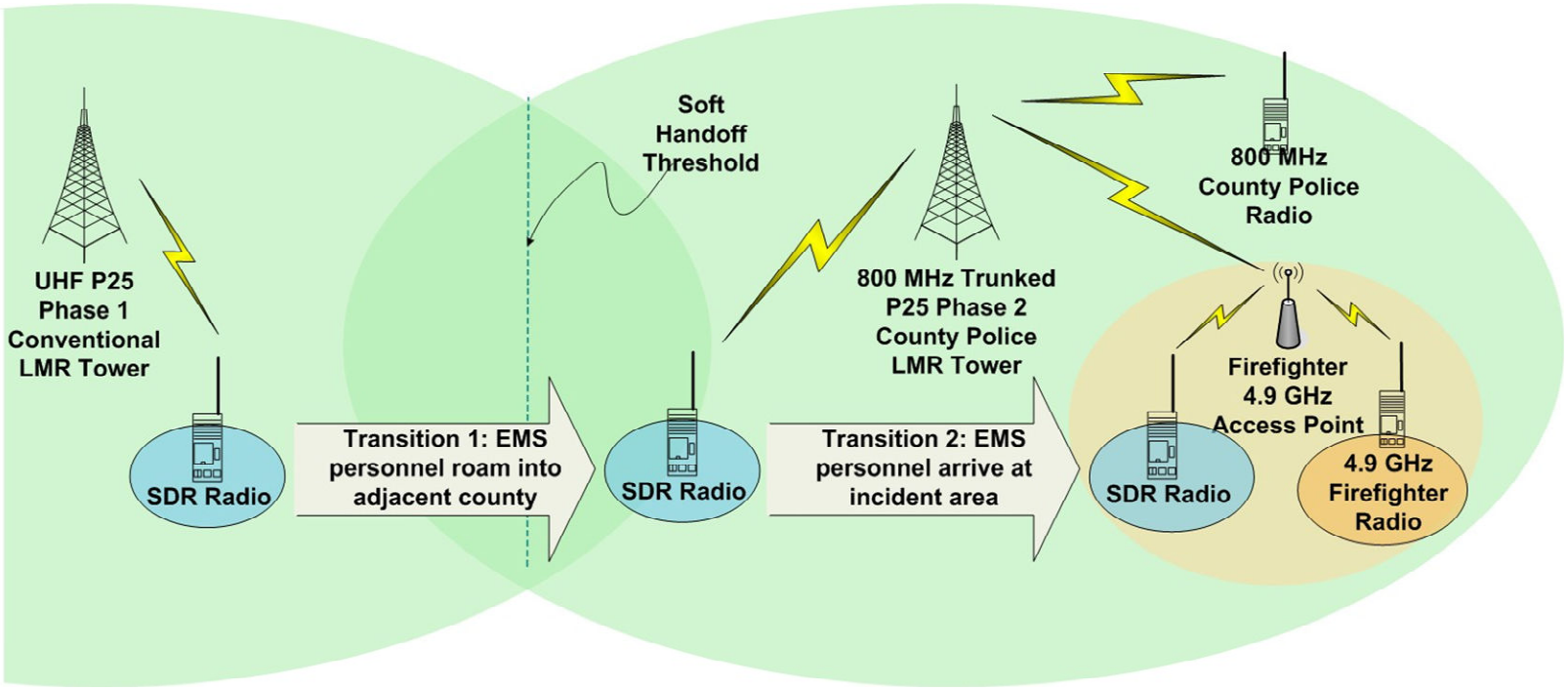
Current interoperability solutions can be broken into four categories—all have associated issues

Solution	Situation	Issues
Swap radios	• Small number of responders that need interoperability • Disparate radio systems	• Requires the use of multiple radios per user • Limited by the number of available extra radios • High cost of maintaining radio cache
Audio switch	• Disparate radio systems • Systems have overlapping coverage footprints	• Spectrally inefficient • Limited number of ports on a switch • Added cost of purchasing switch
Network-based solution	• Pre-established physical connections between systems • Users are within coverage of their home system	• Requires advanced coordination • May require dispatcher intervention • Number of links between systems may be limited • May be expensive depending upon solution deployed
Mutual aid channel	• Radios operate in the same frequency band • No other interoperability solution is readily available	• Only works when all radios are capable of operating in the same frequency band • Only useful for command and control because of limited capacity

Seamless interoperability can be provided by OTA software downloads



Phase 1: EMS Radio communicating with its home system

Phase 2: EMS Radio contacts County Police system via a mutual aid or shared channel and downloads interoperability parameters

Phase 3: EMS Radio is able to communicate directly with first responders at incident scene

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Lifecycle costs could be reduced primarily through lower operations and upgrade costs

- OTA software downloads could help reduce the cost of fixing radio problems by allowing the download of software patches and new parameters
  - Reduces the amount of time to complete the software download because all radios could be reprogrammed at once
  - Saves radio technician time because technicians may not be required to touch every radio
- When adding features or upgrading to a new software version, OTA downloads have the potential to greatly reduce upgrade costs
  - Provides many of the same cost benefits as radio maintenance
  - Does not require a large loaner radio cache because the current radios do not need to be removed from service to perform the upgrade
- In some cases, a critical new feature could be implemented more quickly because there is less risk if the new software fails
  - Reduces risk by allowing quick implementation of an updated version to fix any major software bugs that are encountered
  - Typically, hardware is available that enables the radio to revert to a previous version of software if a problem is encountered

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Interrupted downloads is the first major technical issue that must be resolved to maximize the benefit of OTA downloads

Issue	Potential Solution
Issue #1: **Interrupted Downloads—** Because a radio technician is not present, the radio itself must be able to diagnose an interrupted download and take the steps necessary to correct it	▸ Redundancy can be added to the radio either by housing two complete sets of code on the same storage device or by maintaining redundant storage devices – Redundant memory should not add significant cost, weight, or power requirements to the radio – Storage devices, especially flash memory, is currently used in numerous inexpensive consumer electronic devices (e.g., Apple's iPod) ▸ When an OTA software download is sent, the new version of the software should be installed on only one of the memory devices – Ensures that an operational version of the software is always installed on the radio – Could allow the radio to continue to operate in the event of a failure of one of the devices

The second major issue is airtime requirements

Issue	Potential Solution
Issue #2: **Airtime Requirements—** Downloads requiring a large amount of data to be transmitted at one time could overwhelm the radio system	▸ Transmission packetization—the process of splitting large downloads into smaller, identifiable pieces and completing the download via installments—could reduce the system strain by limiting transmission sizes – To further enhance the efficiency of transmission packetization, a reliable transport layer could be added on top of a broadcast data stream – This process of verifying missing packets could reduce the total number of transmissions ▸ Sending transmissions during off-peak times or at times identified as historically low load reduces the maximum amount of data on the system at a given time ▸ Designating a single channel for OTA software downloads could limit the system resources devoted to the download

The third major issue is roaming and interoperability simplicity

Issue	Potential Solution
Issue #3: **Roaming and Interoperability Simplicity—** When roaming between systems, the process of downloading interoperability parameters must be simplified for the user	▸ A national interoperability channel for OTA software downloads would simplify the process of establishing interoperability – This channel could be used by all local, state, and federal public safety agencies – When authorized, the radios could automatically check the channel when roaming or when interoperability is required in order to receive a download ▸ Standardization is critical for the transmission of interoperability parameters – Not all public safety agencies may be able to afford investing in download software from multiple manufacturers – Under the high-stress atmosphere of a major incident response, radio technicians might not effectively or efficiently run the download software for other radio manufacturers – One key to the success of standardization is the involvement of radio manufacturers and software developers

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In summary, OTA software downloads have great potential for the public safety community

- Potential Benefits
  - OTA software downloads could provide seamless interoperability
  - Maintenance and upgrade costs could be reduced by not requiring radio technicians to physically touch each radio
- Issues and Potential Resolutions
  - Redundant storage devices could reduce the incidence of interrupted downloads
  - Transmission packetization, off-peak transmissions, and the use of a single download channel could minimize airtime requirement issues
- Next Steps
  - The public safety community should gain a better understanding of the benefits and implementation best practices of OTA software downloads
  - Public safety agencies should join forces with the vendor community to define the necessary standards
  - Public safety agencies, in coordination with the Federal Communications Commission and regional planning committees, should focus their efforts on allocating nationwide channels that could be used for the download of public safety interoperability parameters