Advanced Communications Video Over LTE: Efficient Network Utilization Research

First Responders Group

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Prepared for:	**The First Responders Group Office for Interoperability and Compatibility by Johns Hopkins University Applied Physics Lab**

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Contact Information

Please send comments or questions to: SandTFRG@HQ.DHS.GOV

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1 PROBLEM STATEMENT

The capabilities and capacities of Long Term Evolution (LTE) or Fourth Generation (4G) LTE networks are a significant improvement over earlier generation radio access technologies, but the network resources are still expected to be limited, especially during emergency incidents due to higher demand. The resources required to support video over wireless networks are significant. The demand for such services is expected to be high on the Nationwide Public Safety Broadband Network (NPSBN). As such, research is needed as to the efficient utilization of NPSBN bandwidth for the transmission of video content. This memorandum report provides relevant background on video data and LTE; proposes a framework for considering the wireless transmission of video in a holistic fashion; and recommends areas for additional study.

2 BACKGROUND

2.1 INTRODUCTION

In February 2012, the U.S. Congress passed the Middle Class Tax Relief and Job Creation Act [1], which created a requirement to establish a national public safety broadband network known as the NPSBN. The Third Generation Partnership Project (3GPP) [2] LTE technology was selected as the basis of this next generation broadband network. The First Responder Network Authority (FirstNet) was created within the National Telecommunication and Information Administration (NTIA) of the Department of Commerce to provide the first high-speed broadband nationwide network for public safety.

The process to deploy the nation's first broadband network should be strategically planned and considered. Potential operational issues can be minimized or avoided by planning for key network services. One such service is video. The demand for this service would likely be high, especially during emergencies, so the limited supply of LTE resources has to be managed efficiently.

The NPSBN will be a national resource shared among the public safety community (fire, emergency medical services [EMS] and police) and its partners (transportation, public works and utilities). Thus, it is important to establish policies and guidelines to accommodate the diverse needs of this community. To that end, the National Public Safety Telecommunications Council (NPSTC) has established a number of broadband working groups that are currently developing requirements for FirstNet to establish the NPSBN as a shared resource. Similarly, technical research on how to treat video, in particular, is needed to determine the most efficient way to utilize the proposed LTE network.

2.2 VIDEO QUALITY IN PUBLIC SAFETY WORKING GROUP

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) is tasked with organizing and researching the engineering and technological resources of the United States, and leveraging these resources to develop technological tools to help protect the homeland. The DHS S&T First Responders Group, Office for Interoperability and Compatibility (OIC) administers a program entitled *Video Quality in Public Safety* (VQiPS) that is concerned with all aspects of video related to its use in public safety.

In 2008, OIC, within the DHS Office for Interoperability and Compatibility -- formerly the Command, Control and Interoperability Division (CCI) -- worked with the Public Safety Communications Research (PSCR) program of the U.S. Department of Commerce to form the Video Quality in Public Safety Working Group (VQiPS WG). The VQiPS program was created to improve the way video technologies serve the public safety community by partnering with public safety practitioners, federal partners, academia, manufacturers and representatives of standards-making bodies.

To facilitate the process, VQiPS took an innovative approach to coordinate various video standards development activities and provide resources to the public safety community. The VQiPS WG's effort consisted of the following steps: [3]

- Conduct a survey of quality standards and specifications that developed for public safety;
- Create a framework for specific application areas to state their requirements in generalized terms that are common to all (or most) applications;
- Create a guide to assist agencies in mapping these generalized requirements to any existing specifications and standards that might apply to them, even if the specification have been developed for seemingly very different applications; and
- Determine the areas where specifications have not been developed, and guide the current research to these areas.

In July 2012, VQiPS issued a guide for *Defining Video Quality Requirements* [4]. This guide and the accompanying PSCR VQiPS website [6] provide the information and resources necessary to help public safety agencies understand their general video system needs and requirements.

2.3 FIRSTNET'S SERVICES TO THE PUBLIC SAFETY COMMUNITY

FirstNet envisions the NPSBN increasing first responder safety, heightening situational awareness, improving communications and enhancing productivity through public safety centric applications and services. FirstNet's key goals are to meet the needs of the public safety community by providing extensive coverage with reliable mission-critical, high-speed data services. The following questions and answers, taken from FirstNet's website [7][8][9][10], demonstrate FirstNet's vision of the NPSBN and its potential capabilities.

> *HOW WILL THE FIRSTNET NETWORK BENEFIT EMS?*
>
> *Using the FirstNET network will improve situational awareness and decision-making. The FirstNET network will make it possible to use new tools that support faster parallel processing. The FirstNet network will enable the exchange of real-time data and audio/video feeds between EMS personnel and hospital staff. This kind of connection, while units are on the scene and during transport, will improve all levels of pre-hospital care.*
>
> *HOW WILL THE FIRSTNET NETWORK BENEFIT THE FIRE SERVICE?*
>
> *Using the FirstNET network will greatly improve situational awareness and keep fire personnel safer with an improved communications capability. The FirstNET network will make it possible to gain quick access to new tools and applications that provide location data and other vital information for firefighting. The FirstNET network will enable the exchange of real-time data and audio/video feeds on the ground to assist incident commanders with operational decision-making and maximize search and rescue and suppression effectiveness.*
>
> *HOW WILL THE FIRSTNET NETWORK BENEFIT LAW ENFORCEMENT AGENCIES?*
>
> *Using the FirstNET network will improve situational awareness and keep law enforcement personnel safer with an improved communications capability. The FirstNET network will make it possible to use new audio reporting tools in the field to gain efficiency. Real-time data and audio/video feeds sent before, during and after incident response will improve the overall effectiveness of law enforcement personnel.*
>
> *WHAT WILL BE POSSIBLE WITH THE FIRSTNET NETWORK FOR FEDERAL DEPARTMENTS AND AGENCIES?*
>
> *The FirstNET network will be built with the goal of enabling faster, more informed and better coordinated responses to incidents and coverage of events. Just as smartphones have changed our personal lives, it is our goal for FirstNET devices*

and applications to change the way federal agencies and other public safety entities operate. Imagine a day when one interoperable communications network can be used to dispatch and alert public safety personnel from different jurisdictions, including many levels of government, all at the same time. It is our goal for federal subscribers and other public safety users of the FirstNET network to be able to share images and applications across multiple databases, allowing a common operational picture to develop as incidents unfold.

As noted in FirstNet's fact sheet of services to the public safety community, video plays an important role in supporting law enforcement agencies, EMS, fire services, and federal departments and agencies. Video services require a large amount of network resources but because the NPSBN will have limited radio resources, careful consideration of resource allocation and minimizing unnecessarily large video files transiting through the network are necessary.

3 MISSION, CONTENT AND TRANSPORT NETWORK (MCTn) FRAMEWORK OVERVIEW

As FirstNet deploys the NPSBN nationally in partnership with the appropriate state, tribal and other public and private entities, the first responder community will have access to new and more extensive multimedia capabilities. The enhancements created through the NPSBN will permit the first responder community to access and exchange a variety of information, such as maps, floor plans, geographic information system (GIS) data and video. Consequently, these enhancements may provide the members of the public safety community with increased situational awareness, improved interoperability and better-coordinated response between different government agencies.

A key service among the host of services available on the NPSBN will be video. As video becomes more integrated into the first responder workflow, the characterization of the minimum video quality needed to support the first responder mission will be critical to the public safety community. First responders may rely on video content not under their control. Access to that content will require agreements with the owners of the video content on how the content will be used and by whom. In addition to providing access, content owners must understand the factors driving video quality to ensure that the video available to the first responders will meet their needs. The transport network must then provide the necessary resources by implementing the appropriate mechanisms to support video as a critical service for public safety missions. The consideration of network resources and first responder mission needs become more crucial during times of peak demand caused by incidents, site outages or unplanned events.

A systematic approach to solving the challenges of efficiently delivering video over a wireless network is needed. During times of resource exhaustion, the tools found in the LTE network alone will likely be insufficient. To deliver this resource intensive service on the NPSBN, a framework consisting of MCTn is proposed (see Figure **1**).

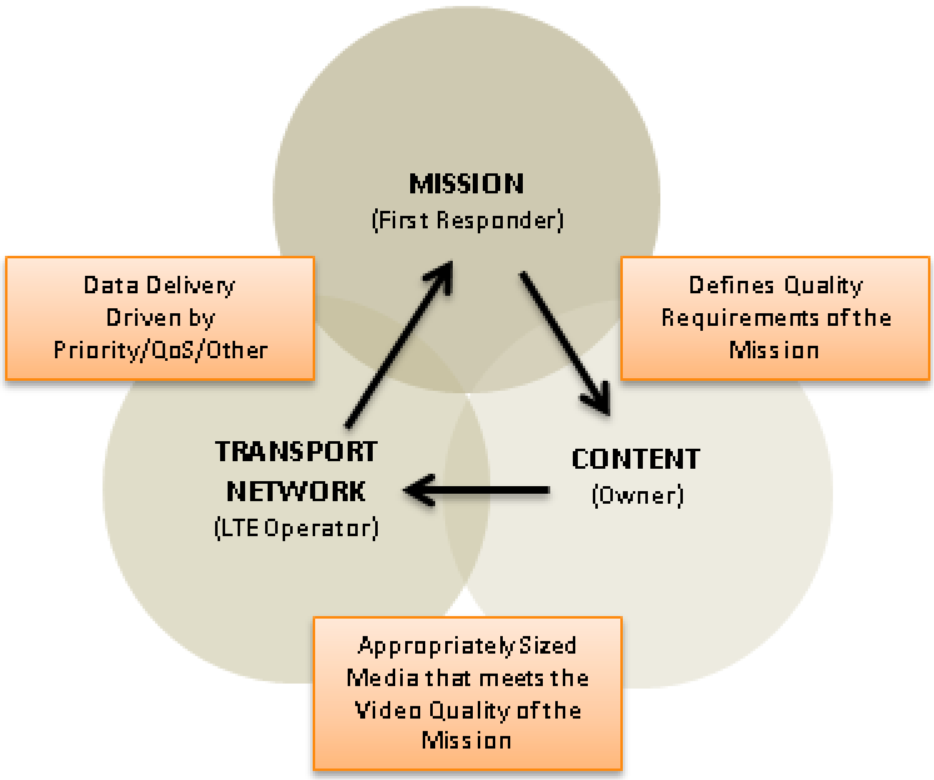

Figure 1: MCTn Framework (Note: QoS means Quality of Service)

This framework introduces several key concepts to help identify, code, control and deliver optimized multimedia content to the intended end user(s), with the goal of keeping the resource requirements as low as possible. The framework provides the means to consider the video quality requirements for the mission and match network resources to the mission need. The following comprises the MCTn framework:

MISSION Component (first responder):

The mission component defines the video quality requirement for the intended purpose and priority of the intended end user(s) to be successful in completing the operational objectives. During times of emergencies or network congestion, the end user ideally receives the video with “just enough” data to meet their requirements, with allocation of network resources on a priority basis. For example, does the user require high definition video to see details in the scene that will allow them to identify a person or object? Alternatively, does the user only need to see general features of the scene to determine the weather conditions?

CONTENT Component (content owner):

The content component introduces the content owner’s responsibility to capture and package video content for distribution to the end user based on the mission needs. What is “just enough” data to meet mission video quality requirements? How should it be coded? What kinds of end user display device capabilities need to be considered?

TRANSPORT NETWORK Component (LTE operator):

The transport network component utilizes tools and features available on the LTE network to prioritize and deliver video during times of congestion or other times of peak demand. For example, during times of congestion, an incident commander may have priority over other users for access to the NPSBN network and resources, so there needs to be a way of allowing priority services to this user. What tools and features can be used to mitigate congestion issues?

To facilitate the flow of data across the NPSBN, the components within the MCTn framework are combined to utilize the LTE network efficiently by balancing the end user’s video requirement with the smallest file size possible with the user priority to meet the needs of the mission.

4 MCTn COMPONENTS

4.1 MISSION COMPONENT

To complete the mission successfully, two factors are important:

1) The ability to make use of the video for its intended purpose; and

2) The delivery of the video to its intended end user(s).

These two factors can help define the mission requirements for video (see Figure **2**). For example, if the mission requires the capability of reading alphanumeric characters, then the minimum video quality should be sufficient to capture and deliver the video with the necessary detail to the end user.

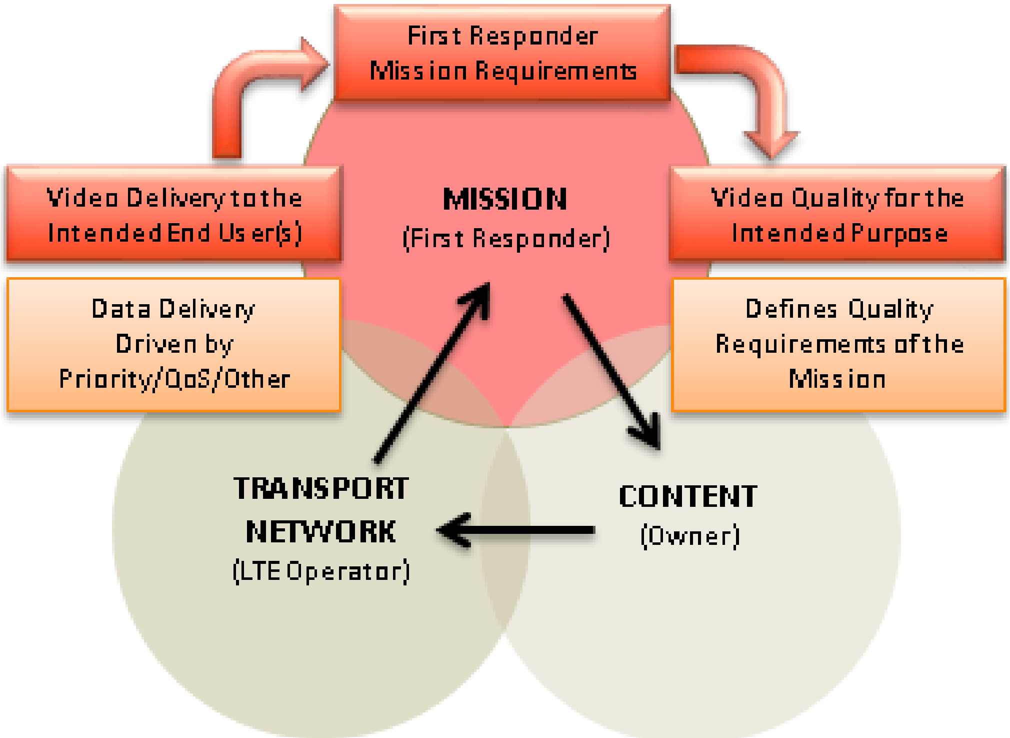

Figure 2: Mission Component (First Responder)

In the MCTn framework, the mission component needs to establish the mission requirements by supplying the necessary information to derive the minimum video quality requirements for the intended purpose and the priority of user and/or application of the intended end user(s).

4.1.1 MISSION VIDEO QUALITY REQUIREMENTS (INTENDED PURPOSE)

The VQiPS WG, referenced in Section 2.2, released the *Defining Video Quality Requirements: A Guide for Public Safety* document in July 2012 [4]. The guide defines video quality as "the ability of the emergency response agency to utilize the required video to perform the purpose intended." Public safety users of video need the ability to recognize a particular target down to a specific discrimination level and the ability to perform a specific task with that information. This fundamentally defines the video quality needed for the intended purpose portion of the mission requirement within the MCTn framework.

To establish the mission requirements for video quality, use cases help specify video quality needs for the intended purpose of the mission. The VQiPS WG, working with the PSCR staff in

Boulder, Colorado, crafted a framework called the Generalized Use Class (GUC) to accommodate these video use cases.

4.1.1.1 VQIPS GUC APPROACH

There are large numbers of possible use cases across different organizations and agencies, but the VQiPS WG found common elements among all or most use case applications. For example, the ability to use video for a facial recognition application to identify a terrorist in real time versus the ability to positively identify a criminal after a crime are two different use cases, but both require high quality video for positive target identification.

The working group applied these common aspects of use cases to general terms and created the GUC framework to accommodate the unlimited scenarios from organizations and agencies when defining video quality requirements.

The five generalized use class aspects, common among different use cases, that can impact video quality are identified in the VQiPS *Defining Video Quality Requirements: A Guide for Public Safety* [4][5] and are summarized below.

1) **Discrimination Level**

   "Specifies a capacity to recognize a target of interest according to a given level of discrimination." Video can be used to identify a wide range of details ranging from general movement to positive identification.

Consider	Use Discrimination Level	Characteristic	Example
What level of discrimination do you need to recognize a target of interest?	High-level description of actions that took place	General elements of the action	People or person present
	Large-scale recognition	Target class recognition	Car vs. van
	Medium-scale detail recognition	Target characteristics	Gender, markings, smaller actions
	Enough detail to make a positive recognition	Target positive ID	Face, object, alpha-numeric

Figure 3: Discrimination Level

2) **Usage Time Frame**

"Specifies whether the video will be used in real-time or will be recorded." Will it be used for live surveillance, tactical command, or record for later use?

Consider	Use Timeframe	Characteristic	Example
In what timeframe will the video be used? For example, will the video be used in real time or will it be recorded?	The video will be viewed at the same time it is being shot	Live or real time	Security monitor being viewed by security personnel
	The video will be saved and capable of being played back	Recorded	Forensic video

Figure 4: Usage Time Frame

3) **Target Size**

"Specify the size of the object of interest with respect to the field of view." Also specifies the region of interest, in relation to the field of view. The larger the region of interest in the overall field of view, the more details can be observed.

Consider	Scene Target Size	Content
What is the size of the object of interest with respect to the field of view?	Large	The target occupies a large percentage of the frame
	Small	The target occupies a smaller percentage of the frame

Figure 5: Target Size

4) **Motion in the Scene**

"Specifies the level of motion you anticipate in a scene of interest." Motion can result from the movement of the target of interest or the capture device itself. Motion can cause the target of interest to blur and affects the length of time the target is in the video frame.

Consider	Scene Motion	Content
What level of motion do you anticipate in a scene of interest?	High	A high-complexity video contains a lot of motion or edges
	Low	A low-complexity video contains little motion or few edges

Figure 6: Motion in the Scene

5) **Lighting Level**

"Specifies the level of lighting you anticipate in a scene of interest." Lighting can be dark or bright, or vary between dark and bright in the frame simultaneously.

Consider	Scene Motion	Content
What level of lighting do you anticipate in a scene of interest?	Constant lighting - bright	At a comparatively bright level
	Constant lighting - dim	At a comparatively dim level
	Variable	Ranges from bright to dim

Figure 7: Lighting Level

The five aspects common to use cases include discrimination level, usage time frame, target size, motion and lighting level. These combine to create the VQIPS GUC framework (see Figure **8**).

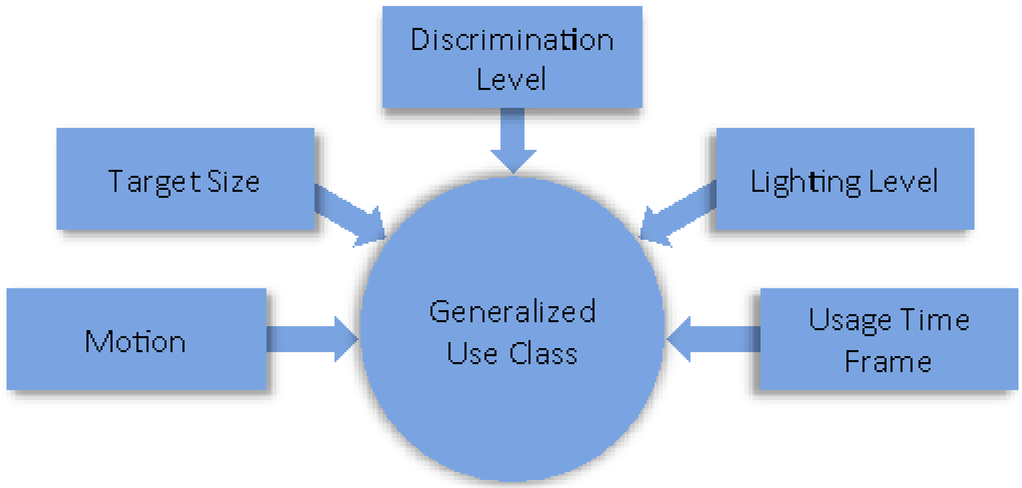

Figure 8: GUC

VQiPS has acknowledged that there are large numbers of possible use cases, but the GUC approach establishes a manageable number of attributes applicable to a large number of use cases. Using this small set of characteristics, the GUC framework can help identify requirements for video quality in the context of a particular mission.

Discrimination level is an important aspect of the GUC because it defines the level of detail needed for a specific task. VQiPS [5] specifies it as having the "capacity to recognize a target of interest according to a given level of discrimination." In other words, it describes the intended purpose of the mission in the MCTn framework.

The four levels of recognition are Target Positive ID, Target Characteristics, Target Class Recognition and General Elements of the Action (see Figure **3**). VQiPS further defines video quality as "the ability of the emergency response agency to use the required video to perform the purpose intended." As mentioned before, the mission requirement determines the video quality needed for the level of discrimination as called for in the MCTn framework. The question of the video quality requirements cannot be reliably answered without knowing the intended purpose (i.e., use) of the video.

With the GUC framework established and the five aspects of the generalized use class tied to the framework, use cases can be applied to the tools and guidelines created by VQiPS [6][13] to identify the relevant video quality requirements.

4.1.2 MISSION COMPONENT SUMMARY

Two factors are important to complete the mission successfully:

1) The ability to make use of the video for its intended purpose; and

2) The delivery of the video to its intended end user(s).

These two factors help to establish the mission requirements. In the MCTn framework, the mission component needs to supply the necessary information to the content owner to derive the minimum video quality requirements for the intended purpose. The VQiPS GUC framework provides the five aspects that affect quality (discrimination level, usage time frame, target size, motion in scene and lighting level), as well as the four levels of recognition (Target Positive ID, Target Characteristic, Target Class Recognition and General Elements of the Action). Additionally, the network must have some understanding of the user and/or application priority of the intended end user(s).

4.2 CONTENT COMPONENT

The ability to use the video for its intended purpose defines the first part of the mission requirement, as mentioned in Section 4.1. To provide the video content that meets the quality requirements of the end user(s), the content owner must understand the specific video quality needs of the mission.

Using the information driven by the mission, the content owner must derive the video quality requirements needed from their video system components to capture and package the video content for transport to the end user. This will involve understanding the bitrate requirements for processed[1] and delivered[2] video quality, capabilities of the end user devices, and selecting the appropriate encoding and decoding (codec[3]) standards for compression and transcoding. The content owner then has to provide network access to this video data.

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[1] Processed Video Quality is the result of image acquisition, capture and image processing on quality.

[2] Delivered Video Quality is the impact of network impairments (if any) on quality.

[3] Codec or coder-decoder used to compress and decompress data for faster transmission.

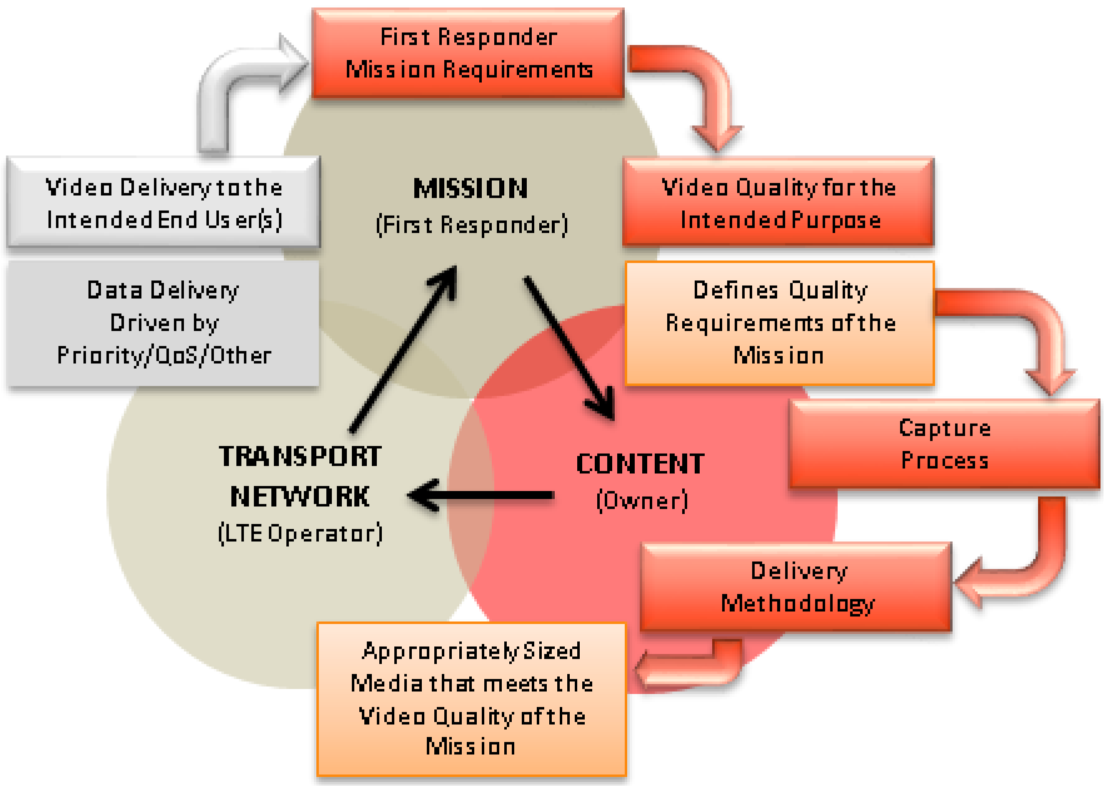

Figure 9: Content Component (Content Owner)

In the MCTn framework, the content component (content owner) should understand the video requirements by utilizing information supplied by the mission (from the end user/first responder) to derive the minimum video quality requirements for the video's intended purpose and provide it to the NPSBN (see Figure **9**).

4.2.1 APPLICABILITY OF USE CASES FOR VIDEO QUALITY

Use cases and the GUC approach provide a useful way to identify the video quality requirements for the mission within the MCTn framework. NPTSC developed the *Use Case & Requirements for Public Safety Multimedia Emergency Services* (MMES) document [11] to identify possible multimedia use cases in public safety. This document was used by Johns Hopkins University/Applied Physics Laboratory (JHU/APL) to identify relevant use cases and variants with applicability to video and video quality requirements (desired detail).

To demonstrate the use of the VQiPS GUC approach, the attributes of the NPTSC use cases were categorized into the five GUC aspects (see Figure **10**). The level of detail desired by the

NPTSC use cases illustrates the various levels of video quality. For example, the detail desired for facial recognition (target positive identification) will likely require high quality video, while lower quality video may be sufficient for general area surveillance (general elements of the action).

USE CASES						
NPSTC USE CASE	VARIANT	DETAIL DESIRED	USAGE TIME FRAME	TARGET SIZE	MOTION	ENVIRONMENT
4	1	Facial recognition*	Real time	Small	Minimal	Indoor
4	2	Recognize a civilian has been injured*	Real time	Small	Minimal	Indoor
4	3	General area	Real time	Small	Minimal	Indoor
4	5	General area	Real time	Small	Minimal	Indoor
4	6	General area	Real time	Small	Minimal	Indoor
9	1	Automatic license reader*	Real time	Small	High	Outdoor
9	2	Facial recognition*	Real time	Small	High	Outdoor
9	3	Video of the suspect vehicle	Real time	Small	High	Outdoor
9	4	Video of the suspect vehicle	Real time	Small	High	Outdoor
9	6	Video of the suspect vehicle	Real time	Small	High	Outdoor
9	7	Aerial video of suspect vehicle*	Real time	Small	High	Outdoor
11	1	Video of officer's exit from a building*	Real time	Small	Minimal	Outdoor
14	1	General area	Real time	Small	Minimal	Indoor
14	7	Video of injuries*	Real time	Large	Minimal	Variable

* Detail cited in the MMES use cases, all others are assumed from references within the context of the use case

Figure 10: Requirements for Use Cases with Video Information

The NPSTC use cases in Figure **10** describe the overall scenario. For example, NPSTC use case 4 describes a scenario involving a hostage incident where a single officer arrives ahead of other responders and is then severely injured. The variants in Figure **10** describe different conditions of the use case scenario where video may be used: 1) the arriving officer captures and transmits video to support facial recognition; 2) an authorized user in the operations center monitors the video to make tactical decisions and shares the video with the response team; 3) once the officer is severely injured, his or her device senses that the officer has fallen and begins video transmission automatically, etc.

4.2.2 GUC APPROACH FOR ENCODED VIDEO QUALITY REQUIREMENTS[4]

The staff at PSCR developed an online tool for video requirements recommendation [13]. The input to the tool consists of the five GUC aspects. This tool, the GUC framework and other references [6] and resources on the VQiPS website [3] were developed to help public safety agencies understand their general video systems needs and requirements.

Among the various outputs from the *Recommendation Tool for Video Requirements*, the encoding bitrate can be obtained. The encoded video bitrate has direct impact on network resources and the level of relative video quality. Although bitrate alone does not exclusively determine video quality, it can reflect the overall video quality and video data size needed for determining network bandwidth requirements.

From previous PSCR VQiPS work, 96 encoded bitrate recommendations can be obtained from the variations across the five GUC aspects. The quality requirements for real-time use versus recorded use were determine to be identical. As a result, 48 different recommended encoded bitrates could be determined by using the remaining four GUC aspects, and its variation determined with the recommendation tool. These combinations were entered into the tool and the resulting encoded bitrates were aggregated into a table (see Figure **11**) to demonstrate the connection between the bitrates and the four GUC aspects: discrimination level, lighting, target size and motion.

[4]This section is a summarization of the JHU/APL *Video Design Improvement Process Report*, Section 3.4, Recommendation Tool for Video Requirements Results.

LIGHTING	TARGET SIZE	DISCRIMINATION LEVEL	HIGH MOTION BITRATE (kbps)	LOW MOTION BITRATE (kbps)
CONSTANT BRIGHT	LARGE	General Elements of the Action	64	64
		Target Class Recognition	64	64
		Target Class Characteristics	128	64
		Target Positive ID	1024	128
	SMALL	General Elements of the Action	128	128
		Target Class Recognition	128	128
		Target Class Characteristics	128	128
		Target Positive ID	256	128
CONSTANT DIM	LARGE	General Elements of the Action	128	128
		Target Class Recognition	256	128
		Target Class Characteristics	512	256
		Target Positive ID	1024	512
	SMALL	General Elements of the Action	512	256
		Target Class Recognition	512	256
		Target Class Characteristics	1024	512
		Target Positive ID	2048	512
VARIABLE	LARGE	General Elements of the Action	256	256
		Target Class Recognition	1024	512
		Target Class Characteristics	1024	512
		Target Positive ID	1024	1024
	SMALL	General Elements of the Action	512	256
		Target Class Recognition	512	1024
		Target Class Characteristics	2048	1024
		Target Positive ID	2048	2048

Source: VQiPS, Recommendation Tool for Video Requirements [13]

Figure 11: Recommended Encoding Bitrate

Several observations can be made when examining the recommended encoded bitrates and discrimination level found in Figure **11**. One can see the correlation between the recommended encoded bitrate and the quality requirements. The highest recommended encoded bitrate of 2048 kbps consists of factors that may contribute to the highest quality requirements with the most challenging GUC aspect conditions, such as "target positive ID" under "variable lighting conditions" consisting of a "small target size." Similarly, the lowest recommended bitrate of 64 kbps consists of factors that may contribute to the lowest quality requirements with the least challenging GUC aspect conditions, such as "general elements of the action" under "constantly bright lighting conditions" consisting of a "large target size." Motion did not have an impact on the recommended encoding bitrate for these two examples.

In general, the recommended encoding bitrate follows the general understanding that higher bitrate results in higher image quality (up to a certain point of diminishing return). As demonstrated above, it is an important parameter having direct impact on video quality and network resource requirements.

In addition to encoding bitrates, other useful recommendations and references are provided by the tool to help the public safety stakeholder understand and minimize the impairment to video quality from video system components illustrated in Figure **12**. More information on the video quality requirements recommendation tool and other resources can be found on the PSCR VQiPS website [3].

The bitrates compiled and associated with the discrimination level in Figure **11** were obtained from the *Recommendation Tool for Video Requirements* [13]. The data used for the recommendation tool are based on the PSCR technical report entitled *Assessing Video Quality for Public Safety Applications Using Visual Acuity* [14]. More information on the report can be found in APPENDIX A.

4.2.3 CORE VIDEO SYSTEM COMPONENTS[5]

VQiPS resources can be used to develop recommendations for core video system component-level requirements. As described in the *Defining Video Quality Requirements* guide and the PSCR VQiPS website, a video system is composed of the functional blocks illustrated in Figure **12**. These blocks consist of six components in the video system reference model: lens configuration, image capture, processing, transport, storage and display.

The video system reference model represents the flow of video information from the image capture process to the video delivery process on the end user's display. At each step, video quality can be negatively impacted, which may result in the inability of the end user to utilize the video for its intended purpose.

[5] This section is a summary of the JHU/APL *Video Design Improvement Process Report*, Section 3.3, Core Video System Components.

The first step in the video system reference model is the capture stage. This is intrinsically an important step. If the camera system cannot see and capture the necessary information or detail, the remaining video system components cannot recreate the missing detail.

As the video progresses through the video system, each component can potentially decrease the quality of the video. The balance between end user video quality requirements and video system component requirements needs to be well managed. It is necessary to consider the video quality needs of the mission in the context of the content quality versus data size and transport network limitations.

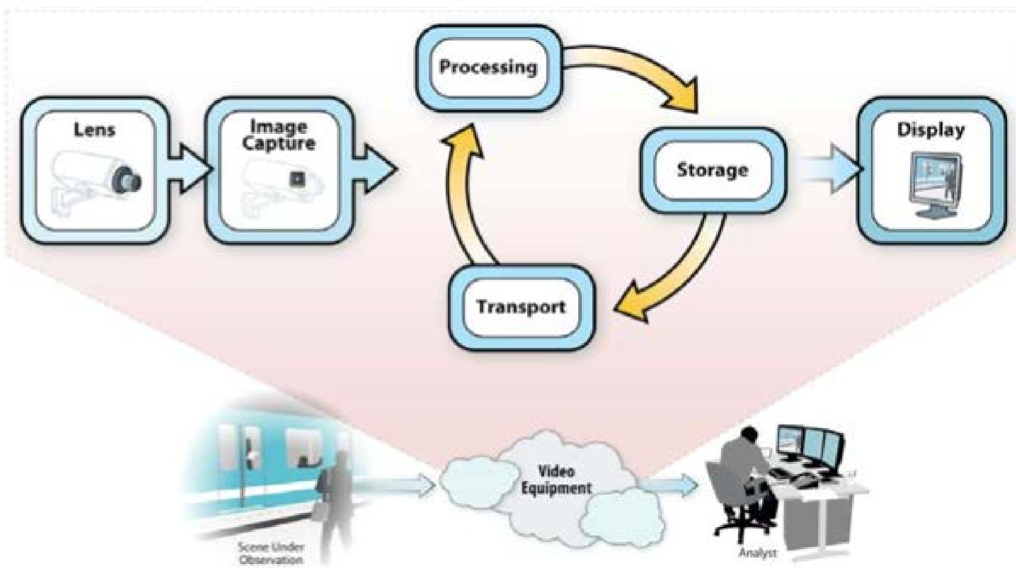

Figure 12: Video System Reference Model [4]

For detailed information on the functional aspects of the video system reference model and possible impact on video quality, refer to the *Defining Video Quality Requirements Guide* [4].

4.2.4 VIDEO PROCESSING TECHNOLOGIES

4.2.4.1 VIDEO COMPRESSION STANDARDS

Video data size can be significant due to the fact that a video file is a sequence of picture files (plus audio, if applicable) over a period of time. The resources needed to support this unprocessed or raw video file can be4come unmanageable. As a result, raw files are typically compressed or encoded to reduce the size of the file. This reduces the bandwidth and storage requirements, while attempting to maintain a certain level of quality.

Selecting the correct codec standard for encoding and decoding can be one of the most important considerations for video processing because it has a direct impact on processed video quality and network bandwidth requirements. Too little compression will result in high video quality, but will yield a large video file resulting in large network resource requirements. On the other hand, too much compression will result in much lower network resource requirements, but the video quality may not meet the needs of the mission. There are various codec standards for video. A description of popular codecs can be found in APPENDIX B.

4.2.4.2 VIDEO TRANSCODING

Transcoding is the process of converting an already compressed video file and changing either the codec or the parameters of the codec (bitrate, quality, image size, etc.). Transcoding is normally used to support transmission over networks with limited capacity and display devices that do not support the original video encoding format. The quality of the transcoded video will be degraded, so content owners need to ensure that the choices made for the original compressed video file will support the quality required by the mission after transcoding. By having multiple versions of the transcoded video format, interoperability between multiple devices with various display and decoding capabilities can be supported. Furthermore, this process allows some aspects of adaptive bitrate support. For example, having multiple versions of the video file with different coded bitrates allows lower bitrate video files to be sent when capacity is limited. Alternatively, higher bitrate video files can be sent when there is sufficient capacity. Further description on transcoding can be found in APPENDIX B.

4.2.4.3 CONTENT DELIVERY

Video delivery technology is evolving continuously. The video delivery system, network protocols and transmission architectures are based on user location, Quality of Service (QoS) and the purpose of the video system. There are several Internet Protocol (IP)-based video delivery systems currently being used by industry today, such as Netflix, YouTube and CISCO. These are commercially viable content delivery providers and vendors, but the technology and system architecture used in these commercial systems may or may not be applicable to FirstNet. Some of these practices can be borrowed and applied to the NPSBN, but other requirements should perhaps be developed by FirstNet to address public safety’s particular needs. For example, the current commercial video delivery methodologies do not consider the matter of priority. Every Netflix user’s video request is treated equally. They are served in the order of first in and first out. This model may not be suitable in the FirstNet environment because important videos can have higher priorities than other videos and may require special treatment for delivery to the intended end user(s). This will be especially important during times of emergencies or peak demand resulting in network congestion. Further description on content delivery technologies can be found in APPENDIX B.

4.2.5 SHARED VIDEO

From 2010 to 2014, JHU/APL worked under a DHS Urban Area Security Initiative Grant to develop a video sharing system for use by a variety of local, state and federal agencies in the National Capital Region (NCR). This system was designed to be interoperable without requiring replacement of existing cameras and video management systems. A JHU/APL fact sheet on the NCR Video Sharing Initiative explained the necessity and benefits of sharing video across the NCR [20]. The concept of shared video between different content owners is an important component of a common operating picture. Through video sharing, improvements in security and situational awareness can be realized by having access to footage, otherwise unavailable, of an area of interest. Additionally, sharing video footage would aid in the planning efforts for pre-response resource management, protection against acts of terrorism, response to disasters (natural or otherwise) and cross agency collaboration.

Regional sharing of video data has become increasingly more important for government agencies to gain situational awareness and enhance emergency response. In the early 1990s, the rapid growth of the population in the Silicon Valley of California was creating vehicular traffic congestion. The City of San Jose installed interconnected traffic surveillance cameras to manage commuter and event traffic. Partnering with other local and regional transportation, transit, enforcement and funding agencies led to the development of the Silicon Valley Intelligent Transportation System as a multi-jurisdictional effort to implement traffic management [23]. Traffic management centers in different jurisdictions were eventually connected by fiber. At the time of initial deployment, an analog video system was used because the Moving Picture Experts Group (MPEG)-1 standard [24] in use at that time could not provide a good quality video. When MPEG-2 [25] was established, the regional governments determined that deploying the high bandwidth network needed to support this standard would be cost prohibitive, so they kept their analog system. As digital technology developed further, they found that they needed a hybrid analog/digital video management system. Encoders were deployed to convert analog video to IP video. They developed a single interface for controlling both analog and digital systems. Thus, they were able to achieve regional video sharing by integrating the legacy analog systems with newer digital technology.

The Baltimore City Police Department's CitiWatch program is another example of video sharing across many different content owners. The city started with 50 cameras in 2005. This program has grown to include more than 635 cameras, with the ability to access over 737 additional cameras from other agencies, e.g., Maryland State Highway Administration and federal and local agencies operating within Baltimore City.[21] In 2014, city officials launched a program in the hopes of quadrupling the number of cameras by including access to private sources [22].

To share video, the participating "content owners" need to provide the means to aggregate the various sources of content at a central location on the network or map the sources of video such that they can be viewed upon an authorized user request. In either design, this will provide access to the available video on the network so that the end user(s) has the capability to pull or be pushed the video data. In the shared video scenario, some sources may not meet the video quality requirements of a specific mission. For example, the video quality of a private camera enrolled in the Baltimore CitiWatch program may not meet the needs of the mission because the source video camera or compression capabilities may be limited.

Sharing video among agencies and other public and private sources can substantially multiply the number of cameras available to the first responder community. The benefits of having a large amount of video sources can be significant; coverage gaps may be minimized, multiple angles of a scene can be obtained, varying quality levels may be available, etc. However, it also presents challenges in cataloging the available cameras and architecting the design of the system to allow discovery of the relevant camera(s) and access by authorized users.

4.2.6 CONTENT COMPONENT SUMMARY

From a content standpoint, the content owner needs to be cognizant of the mission quality requirements, as well as the network requirements. Using the information supplied by the mission component, the content owner needs to derive the video system component specifications and implement them to ensure their video system output can meet the mission requirements.

The MCTn framework proposes the GUC approach as one method for the content owner to determine the mission video quality and network requirements needed to push the video to the NPSBN. Figure **11** shows the recommended encoded bitrates for all combinations of the GUC aspects. The minimum bitrate can indicate both the video quality and network resource requirements. For example, general elements of the action, with variable lighting, small target size and low motion, requires a minimum encoding rate of 256 kbps to satisfy the video quality requirements. This also means that the data pipe in the transport network has to be large enough to support at least 256 kbps (plus overhead) in order to provide the delivered quality.

One additional consideration for the content owner is the expectation of supporting multiple missions over the NPBS. In that case, the video system components need to be selected for the maximum video quality needed to support all the missions, with a transcoding capability to adapt to available network bandwidth.

4.3 TRANSPORT NETWORK COMPONENT

The ability of the intended end user(s) to receive the video defines the second part of the mission requirements, as mentioned in Section 4.1. The transport network needs to receive video data from the content owner (pushed or pulled) that is specifically sized and packaged to be compatible with the end user's device capabilities. These devices may consist of laptops, smartphones or other LTE devices with display capabilities and camera functionality. Each of these devices may be equipped with different display resolution, processing power, codec compatibility, etc.

To deliver video data after accessing it from the content owner, the network needs to understand the minimum delivered video quality requirements and the priority of the end user and application specified by the mission component. Under normal conditions, when the demand does not exceed the designed or planned capacity, delivery of video data at a higher bitrate may not be an issue. When the demand for LTE resources exceeds the designed capacity, congestion will occur. Network congestion can negatively affect the delivered video quality and prevent it from being used to complete the mission successfully. For mission-critical services, this can have negative repercussions.

The tools and features available on the LTE network can be used to prioritize and deliver video during times of congestion or other times of peak demand.

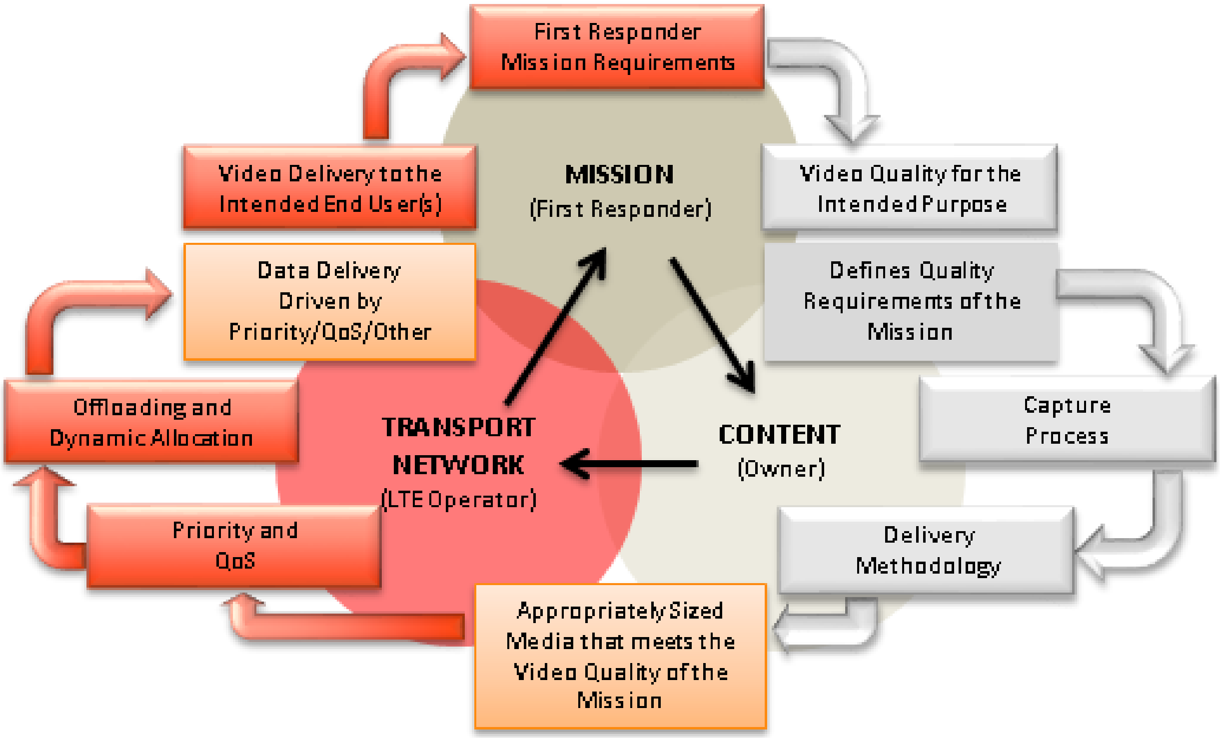

Figure 13: Transport Network Component (LTE Operator)

In the MCTn framework, the transport network component represented in Figure **13** needs to meet the bitrate requirements of mission-critical video pushed by the content owner, and to deliver this video to the intended end user(s). During times of congestion, the tools and features of the LTE network will need to be used to meet the priority and quality needs of the mission. Some of these tools and features include priority and QoS controls and traffic management techniques, such as traffic offloading and dynamic allocation mechanisms.

4.3.1 IMPACT OF LTE CONGESTION ON THE DELIVERY VIDEO QUALITY

Bitrate has direct impact on bandwidth requirements from a transport network standpoint. The recommended encoding bitrate illustrated in Figure **11** indicates the minimum bitrate or bandwidth needed for the data pipe. The available bandwidth or availability of resources on the LTE network has a direct impact on delivered video quality. In other words, if the recommended encoding rate is 2048 kbps, the transport network needs to support that requirement or the delivered video quality will suffer.

Delivered video quality (i.e., the ability to reconstruct the data needed to present the video to the end user) can be affected by congestion contributing to packet losses and packet delays.

Figure **14** shows the types of delivered video quality degradations associated with issues arising from packet losses and packet delays [18].

Types of Transmission Degradation	Degraded Appearance
Block distortion	Distortion in the form of a mosaic or geometric pattern
Jerkiness	Smoothness of movement is lost and the picture appears jerky
Interruptions and frozen images	Intermittent playback/frozen picture
Disturbance (failure)	Original image is irrecoverably lost over some or all of the screen

Source: NTT Network Technology Laboratories, http://www.ntt.co.jp/qos/qoe/eng/technology/visual/01_2.html

Figure 14: Description of Video Quality Degradation

Packet losses can impact delivered video quality due to the loss of actual data and can cause dropouts or pauses in the video. Packet delays impact the sequential reconstruction of the data and can cause the displayed video to be jerky and jittery. Congestion can have an impact on both of these factors.

During times of congestion, restricting access and reserving resources on a priority basis through LTE features and tools can ensure mission-critical video is delivered to the intended user with the required video quality for the intended purpose.

The following sections explore at a high level the features and mechanisms available on the LTE network to manage the access to the air interface and resources, as well as other techniques to provide additional coverage or capacity.

4.3.2 LTE ACCESS AND QoS HIGHLIGHTS

LTE offers a set of tools to allow prioritization of resources based on several methods. These methods allow control of access to the air interface and use of resources once admitted onto the network. The three “stages” of access and resource allocation are illustrated in Figure **15**.

Figure 15: Access to Resources

Access class allows emergency responders to have priority access over secondary users during times of peak demand where available resources are limited or exhausted. The Allocation Retention Policy (ARP) defines the priority level used by admission control during bearer establishment or modification to either accept or reject the request. QoS establishes scheduling priority to ensure time-critical, delay-sensitive applications (i.e., signaling, conversational voice and video) have priority over other non-time sensitive services (i.e., e-mail and chat).

By using these control mechanisms for access and resource allocation, mission-critical services can be assigned resources on a priority basis, while non-mission-critical applications can be deferred or pre-empted until additional resources are available.

Further details on access control and QoS management available on the LTE network can be found in APPENDIX C.

4.3.3 LTE OFFLOADING AND DYNAMIC ALLOCATION

The LTE network has many ways to offload traffic on a severely congested network. The commercial carriers depend on augmenting congested areas with techniques that include adding temporary radio resources with deployable assets, offloading traffic to legacy networks, coverage shaping and data throttling. The FirstNet NBPSN can also utilize these techniques and other features available today and in the future on LTE.

For example, the self-organizing/self-optimization network feature can be used indirectly to improve the network's use by autonomously improving link quality and optimizing neighbor lists in response to cell site outages. Enhanced Multimedia Broadcast Multicast Service may be leveraged to provide one-to-many distribution of video instead of the one-to-one unicast method. Other features that drive network utilization efficiencies with specific applicability to public safety may include group communication and device-to-device communications. Further details on current and future features available in the LTE standards can be found in APPENDIX C.

4.3.4 PRIORITY AND QUALITY OF SERVICE (PQoS) HIGHLIGHTS

A Priority and QoS working group within NPSTC has written a report to the FirstNet Public Safety Advisory Committee (PSAC), which introduces the concept of Priority and Quality of Service (PQoS) [12] beyond the standard 3GPP quality of experience treatment by developing first responder specific PQoS requirements.

This document also helped to highlight additional requirements unique to the first responder community for priority access. The recommendation from NPSTC to the FirstNet PSAC is a high-level guideline for a priority management mechanism based on several key concepts. Some of these capabilities already exist (QoS, pre-emption), but others may have to be further developed, implemented or even standardized (dynamic priority, group priority).

As noted earlier, video uses can vary greatly across the public safety and allied communities. Each of these uses may call for different priorities, which can be seen through the NPSTC MMES use cases [11]. For example, call centers may be processing multiple calls with varying levels of severity, ranging from non-emergencies to major/critical incidents. Further, video for forensic analysis may not be time critical and can be served through best effort delivery on the LTE network; conversely, real-time video may be needed for high-risk crisis incident management or for situations where a first responder's safety is at risk.

To deal with the unique challenges of the public safety community, the NPSTC report proposes three NPSBN priorities: static (default), dynamic and group.

<u>Static Priorities</u>

Static priorities are default priorities designed to handle the day-to-day operation of users and applications utilizing the NPSBN. During times of congestion, these defaults are used to manage priorities so that more critical communications can be assigned the needed resources. The static priority attributes are as follows: type of user, user default role and type of application.

Relative Priority	Applications
1 (Highest)	**Mission Critical Voice** Example: Mission Critical Push-to-Talk Application
2	**Mission Critical Data** Examples: Computer-Aided Dispatch Application, Location Service Application, User Health & Telemetry Application
3	**Mission Critical Video** Examples: Firefighter Helmet Camera Application, Two-Way Video Application, License Plate Recognition Application
4	**Non-Mission Critical Voice** Examples: Telephony Application, Secondary Push-to-Talk Application
5	**Non-Mission Critical Video** Examples: Training and Quality Assurance Video Application
6	**Non-Mission Critical Data** Examples: Text and Multimedia Messaging Application, File Transfers, Web Browsing, Email, Device Management

Figure 16: PQoS Static Priority

The proposed static application priorities are listed in Figure **16** [12]. Generally speaking, mission-critical applications are used for life and property protection, while non-mission-critical applications may be more administrative. These application priorities define the needs of the public safety requirements and should have a comparable corresponding mapping to the 3GPP LTE standardized QoS attributes.

An authorized user entity administrator will typically configure the default priority attributes when a user is added to the NPSBN. Once configured, it would be expected that the default priority would change infrequently.

Dynamic (Situational) Priorities

Dynamic priorities are used to assign temporarily higher priorities during high-risk events involving leadership in the Incident Command System (ICS) role or first responder safety in response to a responder emergency or immediate peril. These priorities are designed to identify the subscriber's current activities in real time and temporarily override the user's default priority based on the situation.

Dynamic priorities will typically require human intervention to initiate, such as pressing a panic button or being assigned to an incident. Triggering dynamic priority should not overburden the end user or administrator, so it should be automatically applied when situations require higher priority over the default priority. For example, higher priority should be automatically configured when a responder triggers "immediate peril" on a device. In addition to device initiation of dynamic priority, other triggers can come from various real-time sources, including Computer Aided Dispatch systems, incident command applications or other mobile device applications installed on the responder's devices.

Group Priority

Similar to the land mobile radio (LMR) assets deployed throughout the public safety agencies, the NPSBN needs to support the concept of a group and be able to apply appropriate priorities to the applications that support group functionality. For example, all the members of a hostage response team will need the same priority assignment to share tactical data communications, such as building maps, onsite video or future LTE-based push-to-talk applications.

The groups can be constructed using unicast resources or broadcast resources. In the unicast resource model, the NPSBN PQoS policies may allow downlink/uplink unicast resources to be combined together for a given group. In the broadcast resource model, LTE provides a point-to-multipoint downlink capability. The uplink will still require unicast resources for this model, but the NPSBN PQoS policy may allow all unicast uplink and broadcast downlink resources to be combined, as a group, and thereby provide similar admission and scheduling priority.

One important distinction between the user priority attributes and group priority attributes is the change from "type of user" to "type of group." This is designed to permit all members within a group to have the same priority assignment to allow a similar level of service across the entire group.

For greater interoperability, the report also recommends standardized policies for managing PQoS functions while allowing sufficient flexibility to meet local operational requirements and large-scale incidents. To this end, the NPSBN PQoS framework must also accommodate the use of the ICS by prioritizing the responder based on the responder's assigned incident role. As previously mentioned, the trigger to temporarily overwrite the default priority and initiate dynamic priority for ICS can come for an incident command application.

The NPSTC PQoS report [12] touches upon several high-level concepts to support the unique needs of the public safety community. Some of the concepts may be implemented with the current set of LTE tools, but others may need further development and standardization by the appropriate 3GPP body. It is also important to note that commercial carriers may not have implemented priority service with their network and customers; as a result, the opportunity to leverage the lessons learned from priority service implementation might not exist.

4.3.5 TRANSPORT NETWORK COMPONENT SUMMARY

LTE networks have limited spectral bandwidth and, as a result, will have limited resources available to the end user(s), especially during emergencies. With various applications competing for the resource, resource intensive applications, such as video, can dramatically impact available bandwidth. When congestion occurs, important mission-critical data may not be delivered to the intended end user(s) with sufficient quality to accomplish the mission.

The encoded video bitrate from the content owner has a direct impact on both video quality and bandwidth requirements on the LTE network. If the network cannot support the required bitrate, then the delivery video quality can suffer. The LTE network should strive to deliver mission-critical video, even during times of congestion or peak demand. To manage and prioritize resources during times of congestion, there is a set of tools available on the LTE network to help manage traffic during peak demand. These tools include access and QoS control mechanisms, as well as offloading and dynamic allocation techniques.

5 MCTn SUMMARY

FirstNET's vision is to provide a reliable, resilient, national broadband network dedicated to public safety and allied agencies with a rich set of applications and services to enhance their ability to do their jobs. Video will be a key service among the host of other services available to the public safety community. As video becomes more integrated into the first responder's workflow, it is likely to become a mission-critical service. Video services can be resource intensive and may exhaust LTE resources quickly. This limitation is more critical during times of peak demand caused by an incident, site outages or unplanned events.

Given the potential consumption of bandwidth for this application, the distribution of video across the wireless broadband network must be carefully planned. Careful planning is especially important because both increased demand for video content and increased congestion are likely to occur during emergencies. A framework for planning for this data flow across the main components of the end user(s), content owner and transport network is proposed. It is noted that any one of these components cannot individually address the needs of the mission and efficiently deliver the video data to the end user(s). A more systematic approach is envisioned consisting of the following components: Mission, Content and Transport network (see Figure **17**), referred to as the MCTn framework (see Section 3).

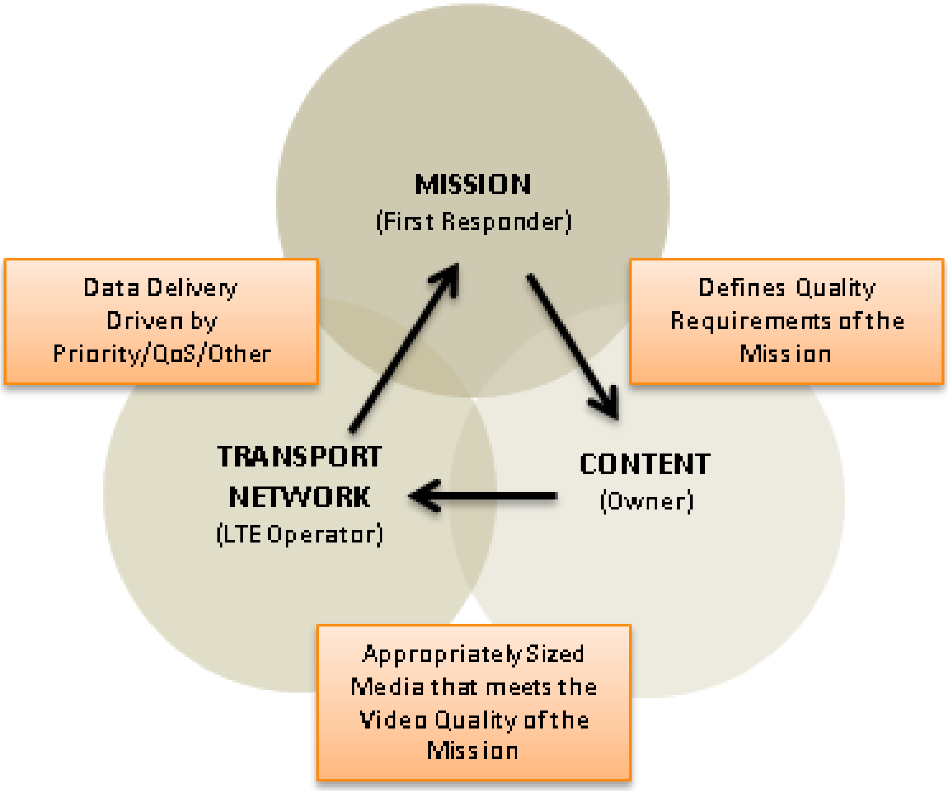

Figure 17: MCTn Framework

MISSION (Section 4.1)

Two important factors can be attributed to successfully meeting the mission requirements: 1) the ability to make use of the video for its intended purpose, and 2) the delivery of the video to its intended end user(s). The mission component needs to establish the video quality requirements and supply the necessary information to the content owner so that the mission video requirements can be understood and applied to the source video system components. Additionally, the network must have some knowledge of the user or application priority of the intended end user(s).

CONTENT (Section 4.2)

The content owner must be aware of the mission video quality and network resource requirements. Using the information supplied by the mission component, the content owner needs to determine the video system component specifications and implement them to produce the desired output meeting mission requirements and suitable for the end user(s) devices(s). This may involve understanding the bitrate requirements for processed and delivered video quality, recognizing the capabilities of the end user devices, selecting the appropriate codec for compression, and transcoding and having the content available to the network (see Section 4.2). Use cases can help to specify video quality needs for the intended purpose of the mission. VQiPS developed the GUC approach to group a variety of video use cases of similar quality and provide tools and resources to help the first responder community develop component level video system requirements (see Section 4.2.2). One key criterion that can impact video quality and network resource requirement is bitrate. The encoded bitrate obtained from the VQiPS video requirements recommendation tool is one way to assess the minimum video quality requirement.

TRANSPORT NETWORK (Section 4.3)

A wireless LTE broadband network offers limited spectral bandwidth resulting in finite resources available to the end user(s). Under normal conditions, when the demand does not exceed the designed or planned capacity, delivery of video and other data may not be an issue. When the demand for LTE resources exceeds the designed capacity, congestion can occur, resulting in video quality that may not meet mission requirements. To deliver video data to the end user(s) during times of peak demand, the network needs to understand the minimum delivered video quality requirements to fulfill the mission need and the priority of the end user and application specified by the mission component. This information will then allow the network operator to prioritize and manage wireless resources by using a set of LTE tools to deliver the video (see Sections 4.3.2 and 4.3.3). These tools can include access and QoS control mechanisms, as well as offloading and dynamic allocation techniques.

A Priority and QoS working group within the NPSTC has proposed to FirstNet the concept of PQoS to address the needs of the first responder community (see Section 4.3.4). The PQoS model identifies *static* (default), dynamic and group priorities. Static priorities are used for day-to-day operation of the network, while dynamic priorities are used for situations where the default priority is temporarily overwritten to allow higher priority access to the NPSBN. For example, an incident commander involved in a crisis should be automatically provisioned for higher priority access to the network. The PQoS concept also introduces the idea of group priority, similar to LMR, where the same priority has to be assigned to members of the same group to share tactical data. Some of the concepts may be implemented with the current set of LTE tools, but others may need further development and standardization by the appropriate 3GPP body.

Mission, Content and Transport Network combine to form the MCTn framework for the delivery of video from a holistic standpoint. Each component has functional inputs and outputs (shown in Figure **18** and outlined below), which need to be shared with each of the MCTn partners to meet the needs of the mission.

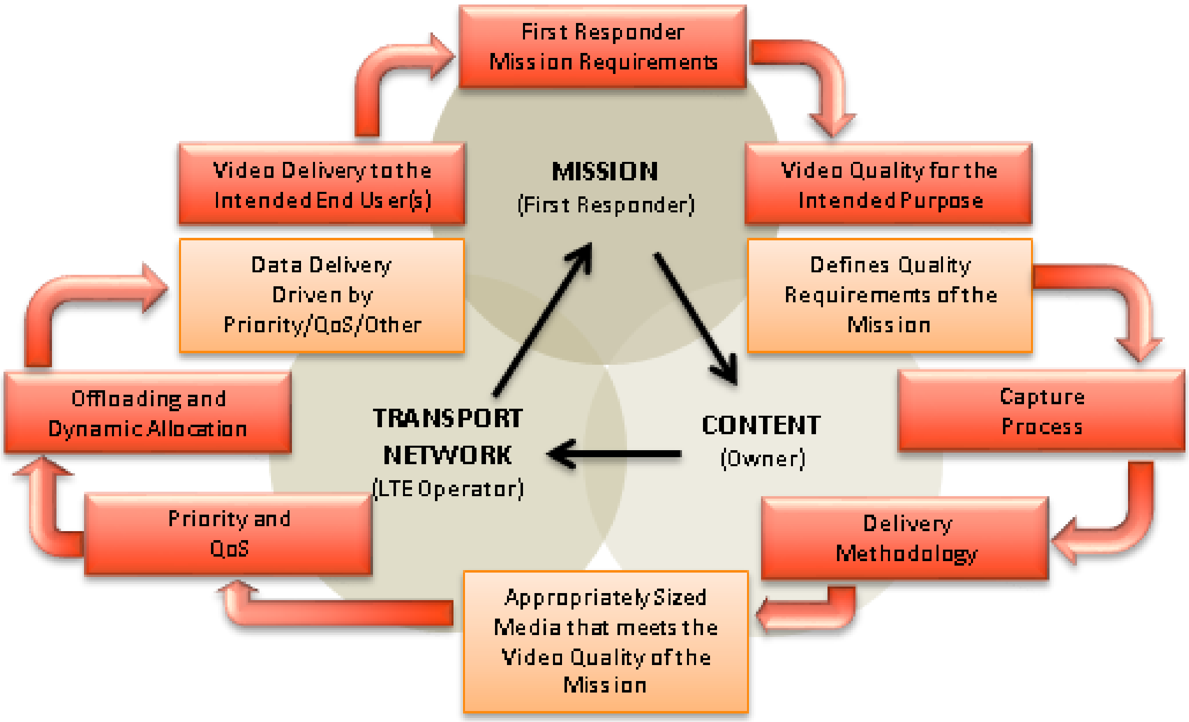

Figure 18: MCTn Functional Objectives

<u>Functional Objectives Summary</u>

- MISSION Component (First Responder):
    - Establishes the intended purpose: minimum video quality
    - Establishes the intended end user(s): priority
- CONTENT Component (Content Owner):
    - Understands video quality requirements: minimum for the mission
    - Produces the desired output, suitable for the end user(s) device(s): appropriately sized media, meeting video quality of the mission
    - Makes content available to the network
- TRANSPORT NETWORK Component (LTE Operator):

- Aware of the user and application priority
- Understands the delivered quality requirements
- Uses LTE tools and features to deliver video with sufficient quality to the end user(s) during times of peak demand

6 HIGH LEVEL SUMMARY OF METHODOLOGIES

6.1 CURRENT METHODOLOGY

6.1.1 BENEFITS

The video coding and transcoding technologies have made great progress during the last 20 years by enhancing processed video quality while lowering network resource requirements. Many video coding standards and configurations are available to support the needs of the mission. As described previously, these video compression technologies can be selected to fulfill the requirements of different use cases and accommodate the conditions of delivery networks.

For video content delivery, current commercial video solutions focus on providing streaming video content to their subscribers. They take advantage of the bandwidth capability of existing wireline networks with architecture designed specifically for video delivery, such as Content Delivery Network technology. In addition, web browsers are considered as video display interfaces via a robust video plugin.

Video delivery today makes sophisticated use of feedback from the video decoder to allow video quality to adapt to network conditions by delivering video at different bit rates, hence, quality levels.

6.1.2 CHALLENGES

Many of the NPSTC's use cases involve interactive real-time video. These use cases are time sensitive and have high quality requirements, so the network will need to meet stringent packet delay and loss requirements. By comparison, the packet delay and loss requirements are more relaxed in the commercial wireless video content delivery networks because these services currently operate on a best effort basis.

The NPSBN intends to use the resource limited wireless LTE network as the last link to deliver the necessary video data to complete the mission. During non-peak times, delivered video quality may not be impacted. During times of peak demand, however, the delivered quality can quickly deteriorate due to limited bandwidth. In comparison, while bandwidth is still a concern for wireline networks, the available bandwidth is substantially larger.

The FirstNet video requirements are complex because they involve mission-critical applications and need to support various display devices (monitors, laptops, tablets, handsets, etc.); applications (interactive and streaming); delivery networks (wireline, wireless-LTE); and mobility support (stationary, high speed), among others. Overall, the delivered video quality on the LTE network needs to support the mission of the first responder, while balancing the demand for the limited wireless resources.

6.2 MCTn FRAMEWORK METHODOLOGY

6.2.1 BENEFITS

The end user(s), content owner and transport network cannot efficiently address the needs of the mission requirements independently. For example, if the content owner is not aware of the minimum video quality requirements, then the video offered may not be usable by the end user(s). Likewise, if the transport network is not aware of the user or application priority, then the video data targeted for the end user may not be delivered during times of congestion.

The MCTn framework is conceptualized to approach video from a holistic standpoint. The mission component establishes the minimum mission video quality requirement for the end user(s). This requirement needs to be understood by the content component and applied to the video system to produce the desired output. The video data should be in a format suitable for the end user(s) and their device capabilities, and needs to be made available at a location accessible by the network. The transport network component needs to access and deliver the video data while understanding the end user(s) priority and application priority, as well as the minimum delivered video quality requirements. With this awareness, the transport network component can use the tools and features available in LTE to prioritize the delivery of video data to the appropriate end user(s) during times of congestion or peak demand.

6.2.2 CHALLENGES

Mission-critical service requirements are new and relatively unexplored in the commercial world. Most commercial operators manage their networks on a best effort basis. Although the standards have been defined for priority of service, the commercial network operators may not have fully adopted or implemented these features, so they may not be tested and optimized from an implementation standpoint. As a result, prior lessons may not be available for the NPSBN.

Additionally, the end user's priority, the incident severity and the application priority require information external to the carrier. How that information will be standardized and provided to the carrier (FirstNet) has yet to be determined.

Some of the features in the released standards, such as Multimedia Broadcast Multicast Service (MBMS) (Release 6), may still be in the testing phase [17], while other features focused on public safety (e.g., ProSe, Group Com) are currently being drafted by the 3GPP standards body. The full suite of LTE features may not be available for NPSBN implementation in the near term.

As specified by the NPSTC use cases, the real-time acquisition and distribution of video using the LTE network may be a source of congestion for the NPSBN. Traditional forms of video acquisition and distribution rely on wire-based connections (such as coax, cat 5[6] and fiber optics). The bandwidth limitations are less restrictive for wireline connections compared to wireless connections. In the NPSBN, the first and final link may be delivered by an inherently resource limited wireless network. If the available bandwidth cannot meet the video bitrate requirements due to congestion, lack of resources, poor coverage or other factors, the resulting packet delays and losses can negatively impact the delivered video quality and impact mission objectives.

7 AREAS OF THE MCTn FRAMEWORK FOR ADDITIONAL CONSIDERATION

The MCTn framework identifies functional inputs and outputs for each component that form the basis of a collaborative relationship between the end user(s), content owner and transport network provider. To successfully fulfill the mission requirements for the intended purpose (video quality) and deliver that video data to the intended end user(s), various questions related to the functional objectives of the MCTn components need to be answered by JHU/APL and other vested stakeholders (e.g., the first responder community, content owners, FirstNET, VQiPS, PSCR and industry). These questions are outlined below.

MISSION (Participant)

Intended Purpose

- How do participants in the mission establish their video quality requirements?
- How do participants in the mission provide the requirement(s) to the content owner?

[6] Category 5 cable (cat 5) is a twisted pair cable for carrying signals in computer networks.

Intended End User

- How do participants in the mission identify the end user(s)/consumers and their priorities? How is a priority application identified?
- What credentials does the participant in the mission need to provide to access the video content? Who manages those credentials?
- How does the end user "discover" content that may meet the mission need? Will mission related content be "pushed" automatically to the end user?
- How is the need to distribute video to multiple end users conveyed and implemented?
- How can the video be manipulated by the end user, i.e., replay, enlargement, storage, etc.?

CONTENT (Owner)

Produces the Desired Output

- How is the content owner going to understand the mission quality requirements and apply that to their video system output?
- How is the content owner going to be aware of the end user device to provide content suitable for the device capabilities?

Content Available to the Network

- What are the mechanisms to access or deliver video content? Will it be based on a customized App or web browser plug-in? Who will develop these tools and offer it to the first responder community?
- How is shared video between multiple content owners managed and exposed to the network and end user(s)?
- Where does the content owner serve up the video and make it available to the network and the end user?
- How can video content QoS requirements be passed to the transport network provider?
- How does the content owner know to distribute video content to multiple end user(s), for example, to a response team?

- How will user's credentials be authenticated and authorized to allow access to video content and securely deliver it to the end use?

TRANSPORT NETWORK (Provider)

<u>Aware of User/App Priority</u>

- How does the network understand the mission priority of the end user or application and apply it to delivering mission video?

<u>Use LTE Tools and Features</u>

- What type of video service will the transport network provide? Will it offer integrated video services as a distributor, aggregator or just a data pipe provider?
- What tools are available in LTE to help facilitate video delivery?
- What features or techniques are available on the network to provide additional radio resources or utilize available resources more efficiently? How can they be implemented?

<u>Understands Delivered Quality Requirements</u>

- How does the transport network operator know the minimum video quality requirements and provide the necessary bandwidth to ensure delivered video quality is maintained?
- How does the transport network and content provider maintain end-to-end QoS?

The answers to these and other questions will have to be explored by each of the entities involved in the development of the NPSBN. It is recommended that this MCTn framework be introduced to the various partners in this effort and a determination be made as to which parties are best suited to work on the various aspects of efficiently transporting video across the FirstNet NPSBN.

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APPENDIX A RECOMMENDED ENCODED BITRATE BACKGROUND

The bitrates compiled from the tool and associated with the discrimination levels are not intended to suggest that the recommended encoding bitrates will yield a video output with sufficient quality for the use class. The bitrates extracted from the tool, which is based on the Public Safety Communications Research (PSCR) *Assessing Video Quality for Public Safety Applications Using Visual Acuity, Public Safety Communications Technical Report* [1], are the minimum recommended by PSCR and may have other contributing factors impacting video quality. For some recommended bitrates, varying the level of bitrate did not produce acceptable acuity to perform the desired task [1]. As a result, the maximum encoded bitrate was recommended by the study.

The PSCR used the following resolutions and encoder settings (Figure **A1**) for the visual acuity study to arrive at the recommended bitrate. For a small target size, the resolution chosen was 640 x 480 pixels. For a large target size, the resolution chosen was 352 x 288 pixels, but increased to 640 x 480 format for encoding. The files were compressed using H.264 [2] with the settings shown in Figure **A1**.

Parameter	Setting
Profile	Baseline
Level	Automatic
Frame Rate	29.97 fps
Bit rate mode	One-pass CBR (Constant Bit Rate)
Motion Search Range	63
Detect Scene Changes?	Yes
GOP (Group of Pictures) Length	33
B-Frame Count	0
Quantization Parameters	I Picture: 24 P Picture: 25
Entropy Coding Mode	CAVLC (Context-Adaptive Variable-Length Coding)

Source: Assessing Video Quality for Public Safety Applications Using Visual Acuity

Figure A1 : Encoder Setting for Visual Acuity

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APPENDIX B VIDEO PROCESSING TECHNOLOGIES

VIDEO COMPRESSION STANDARDS

Video files can be significantly large in their unprocessed or raw format. Raw video data are comprised of individual, uncompressed picture files (typically with audio) sequenced over time. This can become unmanageable due to huge bandwidth and storage requirements. As a result, raw files are typically compressed or encoded to minimize transport and storage resources.

Video compression can have a positive impact on network bandwidth requirements by reducing the size of the video data. Conversely, it may negatively affect processed video quality. It is one of the most important factors, after the image capture process, contributing to video quality. Too much compression will result in poor processed video quality, while too little compression will result in an unnecessarily large video file size. The goal of video compression is to provide the necessary video quality, while minimizing the size of the video file.

There are many video compression/decompression (codec) standards employed by the industry to minimize the video size for transport and storage. Each has its advantages and disadvantages. A specific codec may offer better compression ratios for a similar level of video quality and yield a lower encoded bitrate.[7]

For example, Figure **B1** shows a comparison between different encoding methods versus the resulting bitrate, while still maintaining the same image quality. As can be seen from the graph, the scene encoded using H.264 [2] (baseline profile) was at least six times more efficient than a scene encoded using Motion JPEG [8], with a comparable level of image quality as shown in Figure **B1**.

[7] Bitrate is the rate at which bits are processed or transferred, typically expressed as kilobits per second (kbps) or kilobytes per second (kBps).

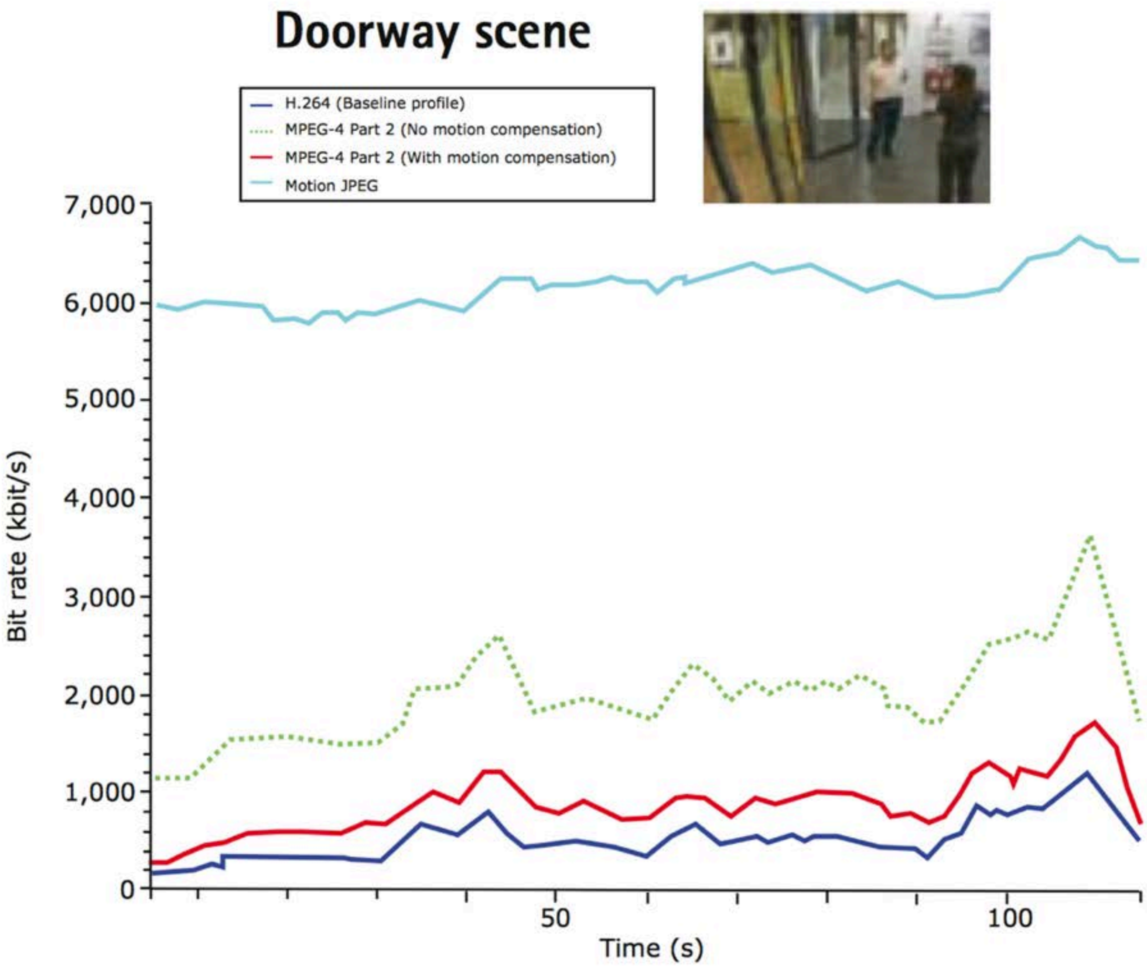

Figure B1 : Comparison Graph of Bitrate Across Various Encoders[8]

Codecs work in tandem to compress the data for transport or storage and decompress the data to display the compressed image. Typically, compression occurs near the source of the video image (on or off camera) and the decompression occurs near the display end of the video chain. Some of the more commonly used codec standards are described next.

H.264/MPEG-4 Part 10 [4]

H.264/MPEG-4 is a block-oriented motion-compensation-based video compression standard developed by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC JTC1 Moving Picture Experts Group (MPEG).

[8] Taken directly from http://www.axis.com/files/whitepaper/wp_h264_31669_en_0803_lo.pdf

The H.264 standard can be viewed as a "family of standards" composed of the profiles. A specific decoder decodes one or more profiles. The decoder specification describes which profiles can be decoded. H.264 is normally used for lossy compression, in which the amount of loss is imperceptible by general viewers.

Recent extensions of the standard included adding five new profiles intended primarily for professional applications.

One major feature added to the standard was Scalable Video Coding (SVC). SVC allows the construction of bit streams that contain sub-bit streams that also conform to the standard. This includes one bit stream known as the "base layer" that can be decoded by a H.264 codec that does not support SVC.

Another major feature added to the standard was Multiview Video Coding (MVC). MVC enables the construction of bit streams that represent more than one view of a video scene. An example of this functionality is stereoscopic 3-D video coding. Two profiles were developed in the MVC work: Multiview High Profile supports an arbitrary number of views, and Stereo High Profile is designed specifically for two-view stereoscopic video.

H.265 [5]

The design of most video coding standards is primarily aimed at having the highest coding efficiency. Coding efficiency is the ability to encode video at the lowest possible bitrate, while maintaining a certain level of video quality. High Efficiency Video Coding (HEVC), designated as H.265, improves the data compression ratio compared to H.264/MPEG-4 AVC at the same level of video quality. It can alternatively be used to provide improved video quality at the same bitrate. HEVC (H.265) is the latest codec standardized by ITU primarily used to support Ultra High Definition Video (4K).

MPEG-2 Part 2 [6]

H.262 or MPEG-2 Part 2 (also known as the MPEG-2 Video) is the second part of the ISO/IEC MPEG-2 standard. MPEG-2 specifies that the raw frames be compressed into three kinds of frames: intra-coded frames (I-frames), predictive-coded frames (P-frames) and bi-directionally-predictive-coded frames (B-frames).

I-frame is a compressed version of a single uncompressed (raw) frame. It takes advantage of spatial redundancy and of the inability of the eye to detect certain changes in the image. Unlike P-frames and B-frames, I-frames do not depend on data in the preceding or the following frames. Briefly, the raw frame is divided into 8 x 8 pixel blocks. The data in each block are transformed by the discrete cosine transform (DCT). The result is an 8 by 8 matrix of coefficients. The transform converts spatial variations into frequency variations, but it does not change the information in the block; the original block can be recreated exactly by applying the inverse cosine transform. The advantage of doing this is that the image can now be simplified by quantizing the coefficients. Many of the coefficients, usually the higher frequency components, will then be zero. The penalty of this step is the loss of some subtle distinctions in brightness and color. Next, the quantized coefficient matrix is itself compressed via coefficients combination and Huffman run-length encoding. This encoding effectively reduces the image data amount significantly.

MPEG-4 Part 2 [7]

MPEG-4 Part 2, MPEG-4 Visual is a video compression format developed by MPEG. It is a discrete cosine transform compression standard, similar to previous standards such as MPEG-1 Part 2 and H.262/MPEG-2 Part 2.

MPEG-4 Part 2 is H.263 compatible in the sense that a basic H.263 bit stream is correctly decoded by an MPEG-4 Video decoder. That is, an MPEG-4 Video decoder is natively capable of decoding a basic form of H.263. In MPEG-4 Visual, there are two types of video object layers: the video object layer that provides full MPEG-4 functionality and a reduced functionality video object layer, which is the video object layer with short headers that provides bit stream compatibility with base-line H.263.

M-JPEG [8]

M-JPEG is an intraframe-only compression scheme. Intraframe compression is less computationally intensive than interframe compression because each video frame contains all the necessary information like a single photo. In contrast, interframe compression group adjacent video frames reference each other and use temporal redundancy to obtain increased compression. While interframe compression uses smaller file sizes than intraframe compression, it requires more processing power because the entire frame group has to be examined instead of a single frame. M-JPEG's lack of interframe prediction limits its efficiency to 1:20 or lower, depending on the tolerance to spatial artifacts in the compressed output. Because frames are compressed independently of one another, M-JPEG imposes lower processing and memory requirements on hardware devices. As a purely intraframe compression scheme, the image-quality of M-JPEG is directly a function of each video frame's static (spatial) complexity. Frames with large smooth-transitions or monotone surfaces compress well, and are more likely to hold their original detail with few visible compression artifacts. Frames exhibiting complex textures, fine curves and lines (such as writing on a newspaper) are prone to exhibit DCT-artifacts, such as ringing, smudging and macro blocking. M-JPEG compressed-video is also insensitive to motion-complexity (i.e., variation over time).

It handles rapidly changing motion in the video stream well, whereas compression schemes using interframe compression can often experience unacceptable quality loss when the video content changes significantly between each frame.

RealVideo [9]

RealVideo is a proprietary video format created by RealNetworks. The early version of RealVideo was based on H.263 technology. After RealVideo 8 was deployed, however, the company switched the video codec to its proprietary video format.

RealVideo can be played from a RealMedia file or streamed over the network using the Real Time Streaming Protocol (RTSP), a standard protocol for streaming media developed by the Internet Engineering Task Force (IETF). However, RealNetworks uses RTSP only to set up and manage the connection. The actual video data are sent with RealNetwork's proprietary Real Data Transport protocol.

VP8/VP9/VP10 [10]

VP9 is an open and royalty free video coding format being developed by Google. VP9 had earlier development names of Next Gen Open Video and VP-Next. VP9 is a successor to VP8, which is an earlier version video compression standard from Google. Chromium, Chrome, Firefox and Opera support playing VP9 video format in the HTML5 video tag. VP10 is the next generation of codec that is under development by Google. VP10 is designed to have better compression efficiency than VP9 by targeting a reduction of the bandwidth requirement by half.

VIDEO TRANSCODING

The transcoding process converts a source video file (typically compressed) and changes the codec and/or codec parameter (bitrate, quality, image size, etc.) to support devices that cannot play the original video format. By having multiple versions of the video, a large set of display devices can be supported through transcoding. This process is normally done by decoding the compressed data using the original codec, then re-encoding the decoded video data with a new codec or the same codec with a new set of parameters [11].

The benefits of video transcoding include codec upgrading, device compatibility and network transport suitability.

Figure **B2** illustrates a video transcoding example in which the same video stream is displayed on different devices (laptop, HD TV and smart phone). Different video codec formats are used in these devices.

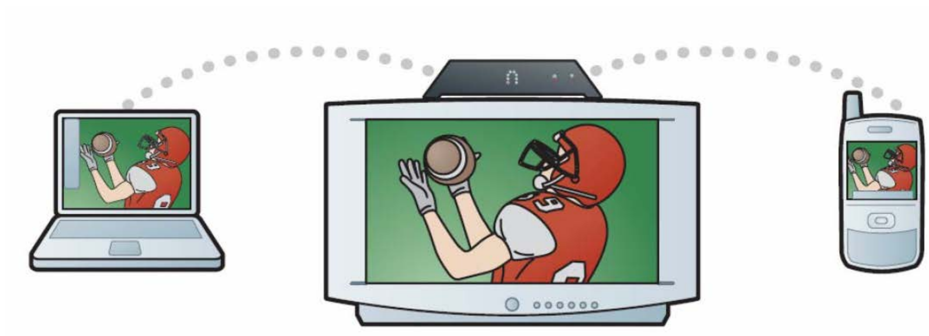

Figure B2 : Personal DVR based Video Distribution Server [11]

It is worth noting that video transcoding normally introduces information loss. This is due to the nature of data losses from different video compression algorithms. Cascading video transcoding will result in degraded video quality.

To mitigate the negative impacts of video transcoding, it is desired to use a common video encoding format. It is also beneficial to support multiple video codecs in the display device to accommodate the various video codecs that may be used to compress video.

VIDEO DELIVERY METHODOLOGY

The technology for video delivery continues to evolve. The video delivery system framework, network protocol and transmission architecture are based on the user location, Quality of Service and the purpose of the video system.

In this section, several industrial video delivery systems are introduced. They can be considered as the current commercial practices for video delivery. The technology and system architecture used in these commercial systems may or may not be applicable to the First Responder Network Authority (FirstNet), however. Some of these practices can be borrowed and applied to the Nationwide Public Safety Broadband Network (NPSBN), but other requirements should be developed by FirstNet to address public safety's needs. For example, in priority service, the current commercial video delivery methodologies do not take into account the priority of requests. Every Netflix user's video request is treated equally. They are served in the order of first in and first out fashion. This model may not be suitable in the FirstNet environment because important videos could have higher priorities over other videos that may require special treatment for delivery to the intended end user(s). This would be especially important during times of emergencies or peak demand resulting in network congestion. This section presents several commercial video distribution models that are considered to be the market leaders in delivering videos to customers.

Netflix Video Distribution Model

Netflix is a commercial movie video content provider that delivers video content to subscribers. Netflix has a capability of delivering movie content to various end user terminals, including desktop computers, laptops, smart phones and tablets. These terminals have different Quality of Experience (QoE) requirements. The movie video contents are delivered via streaming traffic. Netflix network architecture has the following key components:

1) Amazon cloud service and Amazon Web Service (AWS);
2) Content Delivery Network (CDN);
3) Dynamic Streaming over HTTP (DASH);
4) Manifest file to control receiving terminal QoE; and
5) Adaptive video bandwidth control.

Netflix heavily depends on Amazon networking and computing infrastructures to deliver movie content via browser interfaces. It uses the Amazon cloud to store and process its vast amount of video content. Netflix delivers movie content via browser interfaces. AWS is also leveraged to support video delivering services.

A CDN is a system of distributed servers (network) that deliver webpages and other web content to the end users by considering their geographic location. This service is effective in speeding the delivery of content of websites with high traffic and websites that have global reach. The closer the CDN server is to the user geographically, the faster the content will be delivered to the user. CDN also provides protection from large surges in traffic [12].

Netflix uses three CDN vendors: Level3, Akamai and Limelight. These CDN vendors built a network of video servers that are geographically close to the subscribers, which significantly improves the end user QoE.

DASH is the network protocol that Netflix uses to transport video content. In DASH, each video is encoded at several different quality levels and is divided into small "chunks" — video segments of no more than a few seconds in length. The client software requests one video chunk at a time via HTTP. With each download, it measures the received bandwidth and runs a rate determination algorithm to determine the quality of the next chunk to request. DASH allows the player to switch freely between different quality levels at the chunk boundaries.

Netflix video streaming is controlled by instructions in a manifest file that the client downloads. The Netflix manifest file provides the DASH player metadata to conduct the adaptive video streaming. The manifest files are client-specific, i.e., they are generated according to each client's playback capability. For instance, if the user player indicates it is capable of rendering H.264 encoded video, then H.264 format video is included in the manifest file. If the player indicates it can only play Windows Media Video[9] (WMV) format, then only WMV format will be included.

To protect the end user configuration, the manifest file is delivered to the end user via Secure Sockets Layer connection, and hence the content of the file cannot be read over the wire using packet capture tools.

Netflix serves videos in multiple formats and bitrates. When a Netflix client requests the manifest file from Netflix, the client indicates the formats of the content it can play. The Netflix server then responds by sending a manifest file based upon the client request. Each client that has specific video display capability will receive specific video downloading formats and bitrates. These download formats and bitrates are recorded in the manifest file and can be different from device to device.

By using the manifest file, Netflix is capable of adjusting the video traffic data rate and sources. The Netflix video delivery model is suitable for both wireline and wireless transport networks, including the cellular Long Term Evolution (LTE) network.

YouTube Video Distribution Model

Similar to Netflix architecture, YouTube transcodes an uploaded video stream into a set of video streams with different quality. Reducing video quality will reduce required transmission bandwidth. YouTube has an automatic mechanism to adjust video quality according to the end device capability and network condition.

In the network layer, YouTube utilizes the concept of Anycast to provide fast and better video service to the end user. Anycast is a network addressing and routing methodology in which datagrams from a single sender are routed to the topologically nearest node in a group of potential receivers, though it may be sent to several nodes, all identified by the same destination address [1]. By using Anycast, YouTube can quickly find a suitable video server that is near the end user and maintains a balanced load.

[9] Windows Media Video (WMV) was introduced in 1999 and was Microsoft's implementation of the MPEG-4 Part 2 standard.

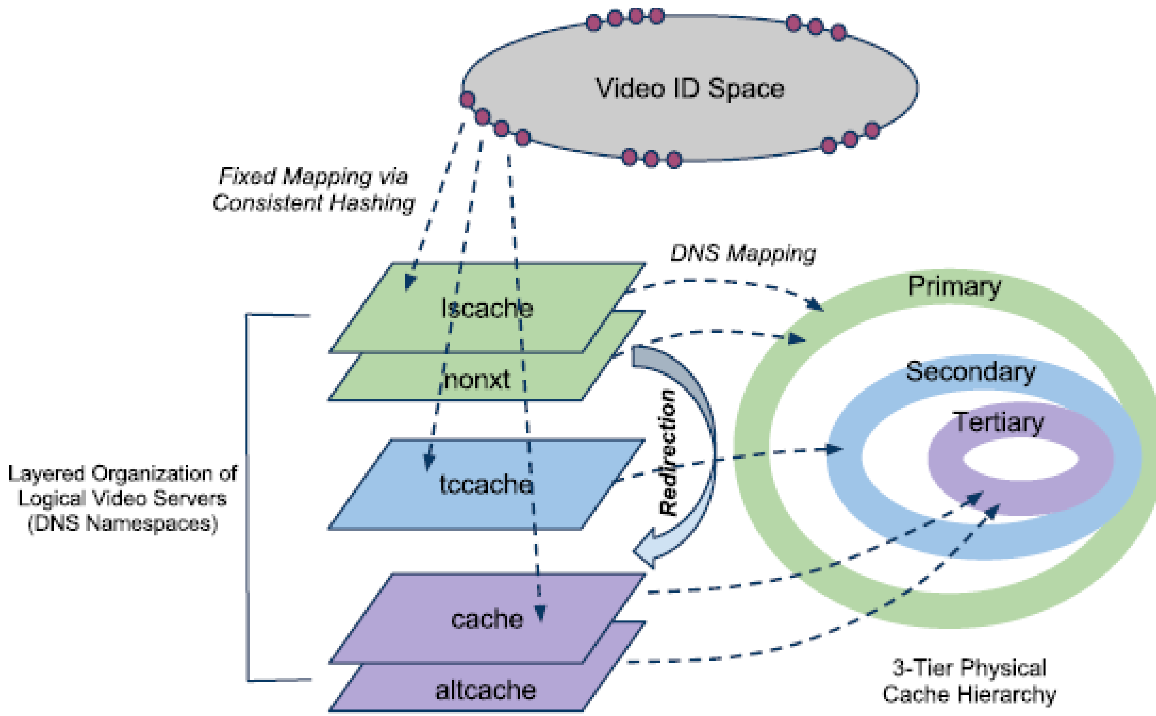

Figure B3 : YouTube Architecture Design [3]

In addition, YouTube utilizes video cache to improve performance. Figure **B3** gives a notional illustration of YouTube architecture. Because YouTube is a proprietary system, it has many features whose sources are hidden.

The following two video delivery methods are from equipment manufactures. They are the reference systems, which may be tailored based on individual customer needs.

CiscoVideo Distribution Model

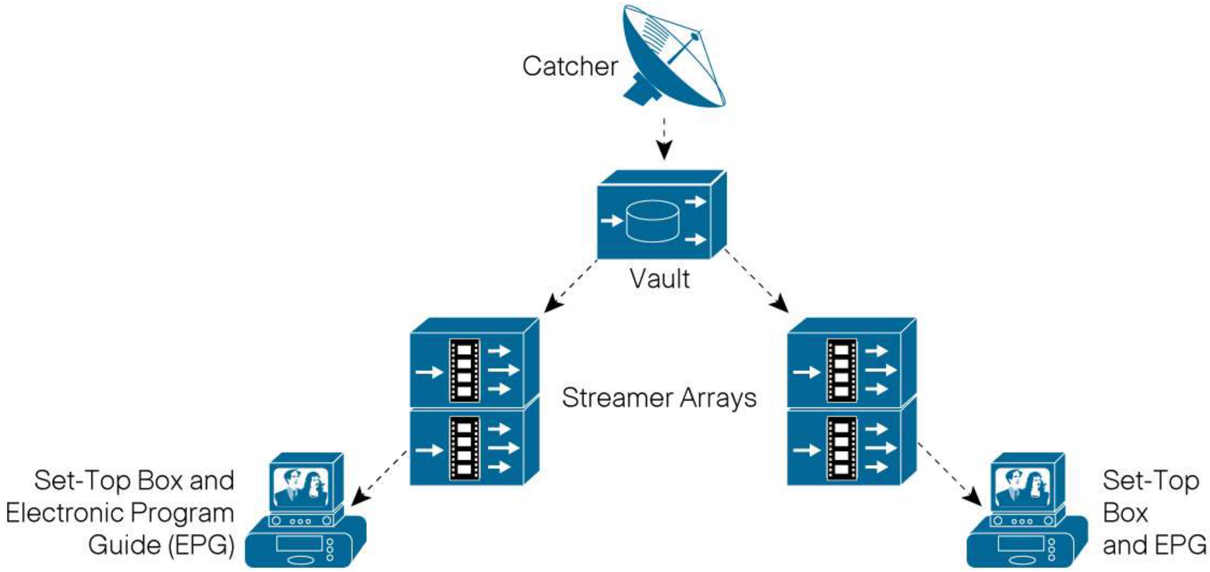

Figure B4 : Cisco's Tiered Content Storage and Streamer Arrays

The Cisco video delivery system is a standard video distribution system with a video signal catcher, which stores the downlink video signal to a vault for temporary storage. Then, the video signal is distributed to individual end users via streamer arrays. Figure **B4** illustrates that architecture is suitable for cable signal distribution.

Motorola Video Distribution Model

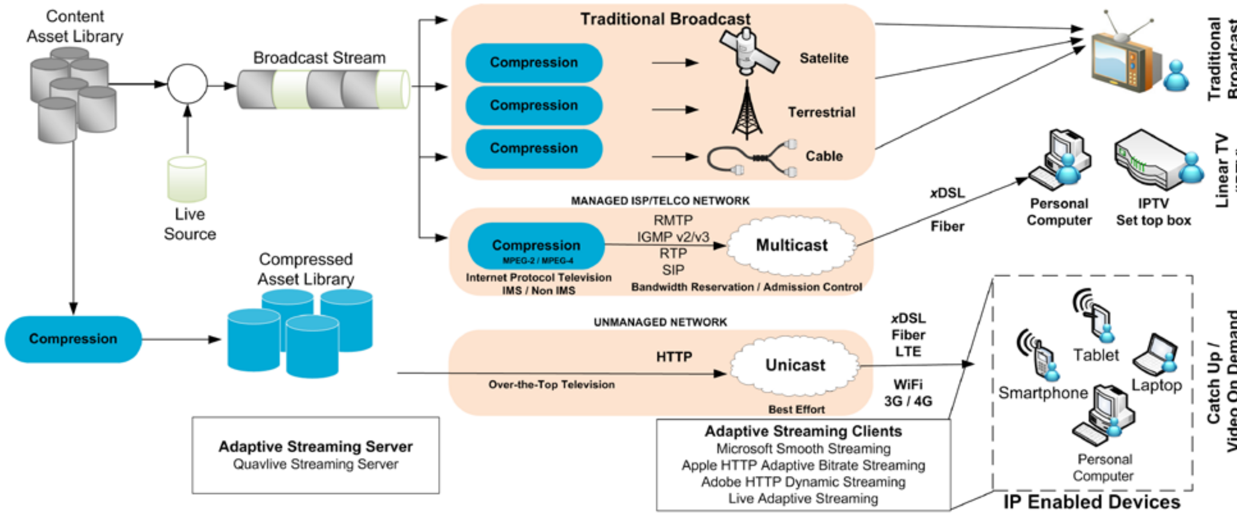

Figure B5 : Motorola's Multimedia Delivery Techniques [13]

Figure **B5** shows an illustration of Motorola's video distribution reference architecture. An adaptive streaming server is included in the system. Both unicast and multicast routing methods are used. This architecture can include different communication media, such as traditional broadcast and Internet Protocol packetized communication and different cellular transport systems, including LTE.

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APPENDIX C LTE NETWORK OVERVIEW AND FEATURES

One of the provisions of the Middle Class Tax Relief and Job Creation Act of 2012 [1] called for the establishment of the Nationwide Public Safety Broadband Network (NPSBN) to operate in the 700 MHz band. This law specified the creation of the First Responder Network Authority (FirstNet) to be built to open, non-proprietary, commercially available standards, which are based on the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) technology [2] and applications. In addition, the law specified that this network be interoperable, so that it is capable of being used by any public safety entity, regardless of their vendor equipment. The Technical Advisory Board for First Responder Interoperability prepared and submitted the final report on "Recommended Minimum Technical Requirements to Ensure Nationwide Interoperability for the NPSBN" [4] for review on May 22, 2012. In addition, the National Public Safety Telecommunications Council (NPSTC) released the "Public Safety Broadband High-Level Launch Requirements – Statement of Requirements for FirstNet Consideration" [5] on Dec 7, 2012. These documents articulate the initial requirements as part of ongoing efforts to improve the delivery of public safety wireless broadband communications in an interoperable manner during emergencies and other times of peak demand.

The NPSBN LTE network is required to have certain tools that can manage and deliver the public safety traffic during emergency situations and other times of peak demand, such as multimedia priority [6], access control [8][9] and resource control [10]. LTE is an all-Internet Protocol (IP) technology platform that is composed of a set of network elements within the 3GPP network architecture. There are three main components:

1) User Equipment (UE), which includes mobile terminations, terminal equipment and the Universal Subscriber Identity Module (USIM);
2) Evolved Universal Terrestrial Radio Access Network (E-UTRAN), which provides radio communications and includes the Evolved Node-B (eNB) base stations for controlling the mobile units in one or more cells; and
3) Evolved Packet Core (EPC), which is the core network.

The E-UTRAN and EPC are collectively designated the Evolved Packet System (EPS).

Figure **C1** shows a basic architecture of the EPS [7] when the UE is connected to the EPC over E-UTRAN. In this figure, the EPC is composed of five network elements: the Serving Gateway (Serving GW); the Packet Data Network (PDN) Gateway (PDN GW); the Policy and Charging Rules Function (PCRF); the Mobility Management Entity (MME); and the Home

Subscriber Server (HSS).[10] The EPC is connected to the external networks, which can include the IP Multimedia Subsystem (IMS) and Packet Switch Streaming .

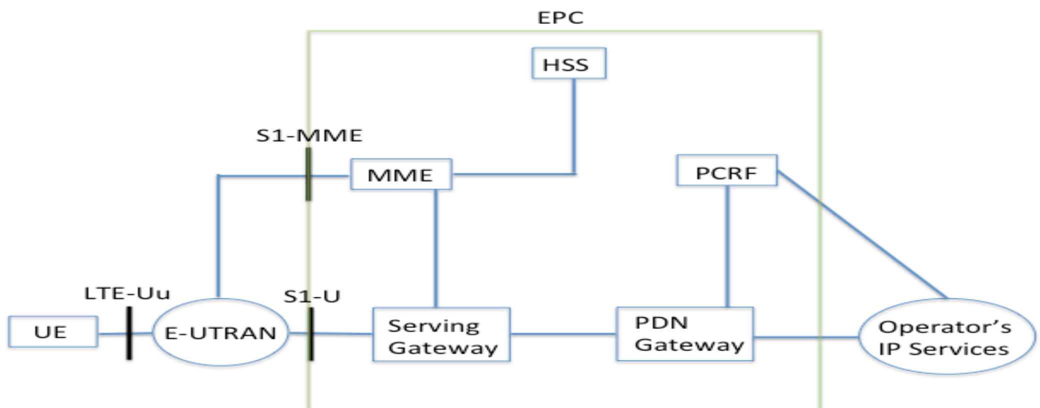

Figure C1 : LTE EPC [7]

The HSS is a database that contains user-related and subscriber-related information, but it also provides support functions such as mobility management, call and session setup, user authentication, and user access authorization. The Serving GW acts as a router for data between the E-UTRAN and the PDN GW. The Serving GW and the PDN GW together are responsible for transporting IP data traffic between the UE and the external networks. The Serving GW terminates the S1-U interface (Figure **C1**) with E-UTRAN, and hosts packet-processing functions such as packet buffering, routing, and forwarding. The Serving GW is also the anchor point for the inter-eNB handovers. The PDN GW is the gateway that provides connectivity to the external IP networks. The PDN GW (or simply P-GW) also performs various functions such as IP address/IP prefix allocation or policy control, and charging enforcement. The MME deals with the control plane, so it handles the signaling related to mobility and security for E-UTRAN access. For example, the MME is responsible for the tracking and the paging of UE in idle-mode. Finally, the PCRF provides Quality of Service (QoS) policy control and flow based charging control decisions. It also authorizes QoS resources and provides usage measurement to support charging.

LTE PRIORITY AND QoS CAPABILITIES

[10] EPC network begins as single node with all functions in one node, except the HSS, which may be kept outside of the node. HSS itself is a node or database, which connects to EPC node Mobility Management Entity (MME) using S6 interface.

During an emergency, not all NPSBN users are treated equally to maintain the necessary level of communications while mitigating network congestion that could slow or halt these communications. Some users, applications and situations require elevated access levels depending on various factors and authorizations, while others will be prevented from making access attempts or responding to communications to reduce the potential network congestion. Furthermore, some situations are of such critical importance that certain NPSBN network traffic should be able to preempt lower priority level traffic. This section captures the LTE prioritization mechanisms that mitigate the potential congestion concerns.

Control Access to Air Interface [8]

An access class (AC) is statically stored in the USIM for each UE.[11] Access classes 0–9 are randomly assigned to commercial users, AC 10 is reserved for Enhanced 911 (E911) calls, AC 11 and 15 are reserved for network administrative devices, and the remaining AC 12–14 are for security services, public utilities and emergency services, respectively. The AC is used by the NPSBN network to control UE access to the network so that access overload can be reduced in times of emergency or network congestion.

The eNB controls user access through a procedure referred to as Access Class Barring (ACB). The NPSBN network broadcasts the ACB parameters in SystemInformationBlockType2. The UE then performs actions according to the access class in the local USIM. For regular users with AC 0-9, access is controlled by ac-BarringFactor and ac-BarringTime. The UE generates a random number that has to pass the "persistent" test for the UE to be granted access. The ac-BarringFactor provides a threshold for access so that setting it to a lower value means that the random number generated by the UE must be lower than this threshold to gain access. While this restricts the access from regular users, priority users with AC 11-15 can access without any restriction. For UEs with AC 11-15, their access is controlled by ac-BarringForSpecialAC, which is a Boolean value: barring or not (see [8]). Similarly, for E911 users (AC 10), their access is controlled by ac-BarringForEmergency, which is a Boolean value: Barring or not. The UE with a special AC (e.g., network administration or public safety users) sends to eNB the "RRCConnectionRequest" [9], which contains the "EstablishmentCause" for "highPriorityAccess" to indicate that it is entitled to priority treatment by virtue of subscription

[11] As machine-type-communications (MTC) continue to burgeon, data and signaling traffic growth in LTE networks is expected in the coming years. MTC may also exist as commercial services in NPSBN. 3GPP LTE advanced (LTE-A) has done comprehensive studies [23][24] on the overload control to manage the data and signaling from massive MTC devices. An overload control mechanism in Release 11 has specified when the network can bar some devices from sending connection requests to the network in case the mass MTC from devices cause E-UTRAN overload and/or core network overload.

to AC 11-15 service. Figure **C2** outlines the four-step contention-based random access procedure[12] with indications of ACB and EstablishmentCause.

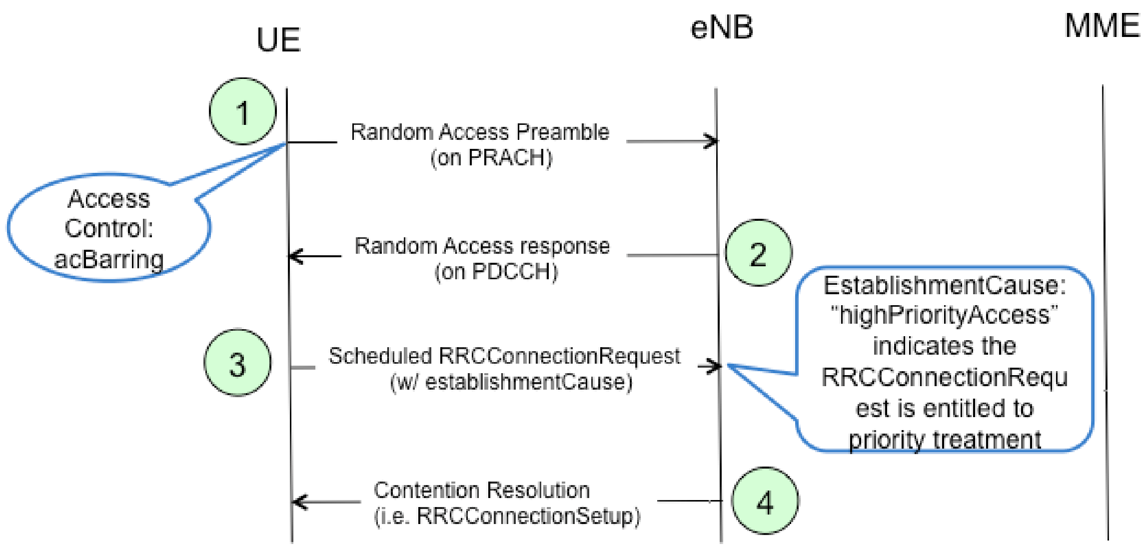

Figure C2 : Four-Step Contention-Based Random Access Procedure [32]

Control Use of Resources

Bearers may be defined as a virtual connection between two or more points in a communications system. EPS bearers are purely packet-switched and provide the UE access to PDN services and applications (Figure **C3**). An EPS bearer is the level of granularity for bearer level QoS control in the NPSBN network. That is, Service Data Flows (SDF) mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g., scheduling policy, queue management policy, rate shaping policy and radio link control configuration) [32]. The default EPS bearer is established during attachment and maintained throughout the lifetime of the always-on IP connection. Additional dedicated EPS bearers can be established dynamically as a result of service requests or access to services. Once the NPSBN has determined that resources should be granted, QoS scheduling priority attributes control use of resources (i.e., when and how traffic should be sent or received from the UE device). Like control access priority, NPSBN network typically assigns QoS to the UE application.

[12] 3GPP LTE access protocol also has contention-free (or non-contention-based) method. The non-contention-based method is used when users have dedicated orthogonal preambles. The non-contention-based access method is used, for example, in handover cases.

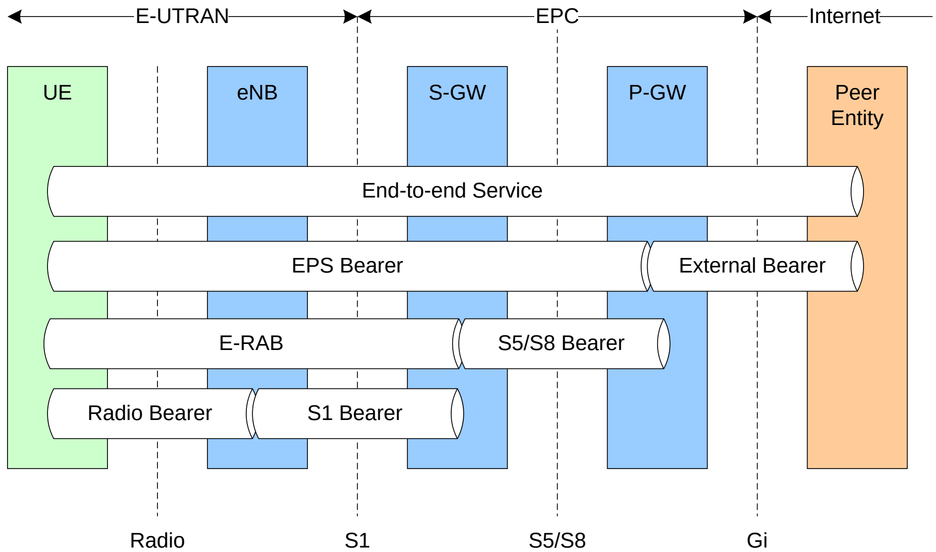

Figure C3 : EPS Bearer Service Layered Architecture [32]

In the NPSBN LTE network, the EPS bearer QoS is controlled using the following QoS parameters [7]:

- QoS Class Identifier (QCI)
- Allocation and Retention Priority (ARP)
- Guaranteed Bit Rate (GBR)
- Maximum Bit Rate (MBR)
- Access Point Name (APN) – Aggregate Maximum Bit Rate (AMBR)
- User Equipment Aggregate Maximum Bit Rate (UE-AMBR)

QCI

The QCI is particularly important because it serves as a reference in determining QoS performance characteristics for each EPS bearer. The QCI controls the packet forwarding treatment (e.g., scheduling weight, queue management thresholds and link layer protocol configuration). QCI is typically pre-configured and assigned by the NPSBN network. QCI values are standardized to reference the specific QoS performance characteristics (Figure **C4**), such as resource types (GBR or non-GBR), priority (1–9 or 65-70), packet delay budget (allowed packet delay in values from 50 ms to 300 ms) and packet error loss rate (allowed packet loss in values from 10^{-2} to 10^{-6}).

In the case of bandwidth-related bitrates, GBR and MBR are associated only in the GBR type of EPS bearers. AMBR is only associated in the non-GBR type of EPS bearers (i.e., AMBR is the sum of all non-GBR bearers per UE/Access Point Name).

QCI	Resource Type	Priority Level	Packet Delay Budget	Packet Error Loss Rate (NOTE 2)	Example Services
1 (NOTE 3)	GBR	2	100 ms (NOTE 1, NOTE 11)	10^{-2}	Conversational Voice
2 (NOTE 3)	GBR	4	150 ms (NOTE 1, NOTE 11)	10^{-3}	Conversational Video (Live Streaming)
3 (NOTE 3)	GBR	3	50 ms (NOTE 1, NOTE 11)	10^{-3}	Real Time Gaming
4 (NOTE 3)	GBR	5	300 ms (NOTE 1, NOTE 11)	10^{-6}	Non-Conversational Video (Buffered Streaming)
65 (NOTE 3, NOTE 9)	GBR	0.7	75 ms (NOTE 7, NOTE 8)	10^{-2}	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66 (NOTE 3)	GBR	2	100 ms (NOTE 1, NOTE 10)	10^{-2}	Non-Mission-Critical user plane Push To Talk voice
5 (NOTE 3)	Non-GBR	1	100 ms (NOTE 1, NOTE 10)	10^{-6}	IMS Signalling
6 (NOTE 4)	Non-GBR	6	300 ms (NOTE 1, NOTE 10)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (NOTE 3)	Non-GBR	7	100 ms (NOTE 1, NOTE 10)	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8 (NOTE 5)	Non-GBR	8	300 ms (NOTE 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9 (NOTE 6)	Non-GBR	9			
69 (NOTE 3, NOTE 9)	Non-GBR	0.5	60 ms (NOTE 7, NOTE 8)	10^{-6}	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70 (NOTE 4)	Non-GBR	5.5	200 ms (NOTE 7, NOTE 10)	10^{-6}	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)

Figure C4 : Standardized QCI characteristics [10]

The Policy Control Enforcement Function (PCEF) administers the policy and charging rules. For reference, packet delay budget is the delay budget between a PCEF and a radio base station and packet error loss rate is between the UE and the radio base station on the air interface. For more details on this and other notes related to the QCI characteristic, please refer to the *Policy and Charging Control Architecture* standard, TS 23.203 [10]. Note that the QCI table in Figure **C4** is for Release 13 standards. Public safety centric services are being developed for Release 12. As a result, public safety QCI characteristics are reflected in the standardized table (e.g., mission-critical push to talk voice).

ARP and Pre-emption

The QoS parameter ARP [10] contains information about the priority level, the pre-emption capability (i.e., can pre-empt other users) and the pre-emption vulnerability (i.e., can be pre-empted by other users). The priority level defines the relative importance of a resource request. This allows for deciding whether a bearer establishment or modification request can be accepted or needs to be rejected in case of resource limitations (typically used for admission control of GBR traffic). It can also be used to decide which existing bearers to pre-empt during resource limitations. It is suggested that NPSBN be designed to pre-empt applications before it pre-empts users.

ARP priority levels range from 1 to 15, with 1 being the highest level of priority. The pre-emption capability information defines whether a service data flow can get resources that were already assigned to another service data flow with a lower priority level. The pre-emption vulnerability information defines whether a SDF can lose the resources assigned to it to admit a SDF with higher priority level. The pre-emption capability and the pre-emption vulnerability can be set either to 'yes' or to 'no’. ARP is considered only when bearers are created or modified. Once a new bearer is created and packets are delivered through it, the ARP does not affect the priority of the delivered packet, and thus the NPSBN network forwards the packets regardless of their ARP values.

At every Radio Bearer (RB) setup request, including handoff and Radio Resource Control connection re-establishment, the eNB Radio Admission Control entity checks the current eNB’s ability to accept the request, considering factors such as maximum number of UEs and RBs, number of RBs on GBR, and hard capacity limit.

Rate Limiting and Bandwidth Management (GBR, MBR, APN/UE-AMBR)

While a NPSBN LTE network offers state-of-the-art spectrum efficiency to deliver the public safety services, its capability and capacity are still limited due to spectrum constraints, as well as likely financial constraints. As a result, it is important to ensure that the data rate and bandwidth from an UE do not consume more resources than required. This is especially true for video services where the resources needed to support such services can be high.

Rate limiting and bandwidth management provide public safety with the ability to control the amount of over-the-air resources that are made available to a given UE. This will prevent a single public safety user from dominating resources at an eNB. Depending on how many applications and/or services a UE is using, there can be many IP flows (VoLTE, YouTube, etc.). These IP flows are mapped to an SDF in a PDN-GW. The PDN-GW processes QoS at the SDF, maps them to the EPS bearer, and delivers the EPS bearers to the UE. Technical detail of LTE's standard rate limiting capabilities is illustrated in Figure **C5**.

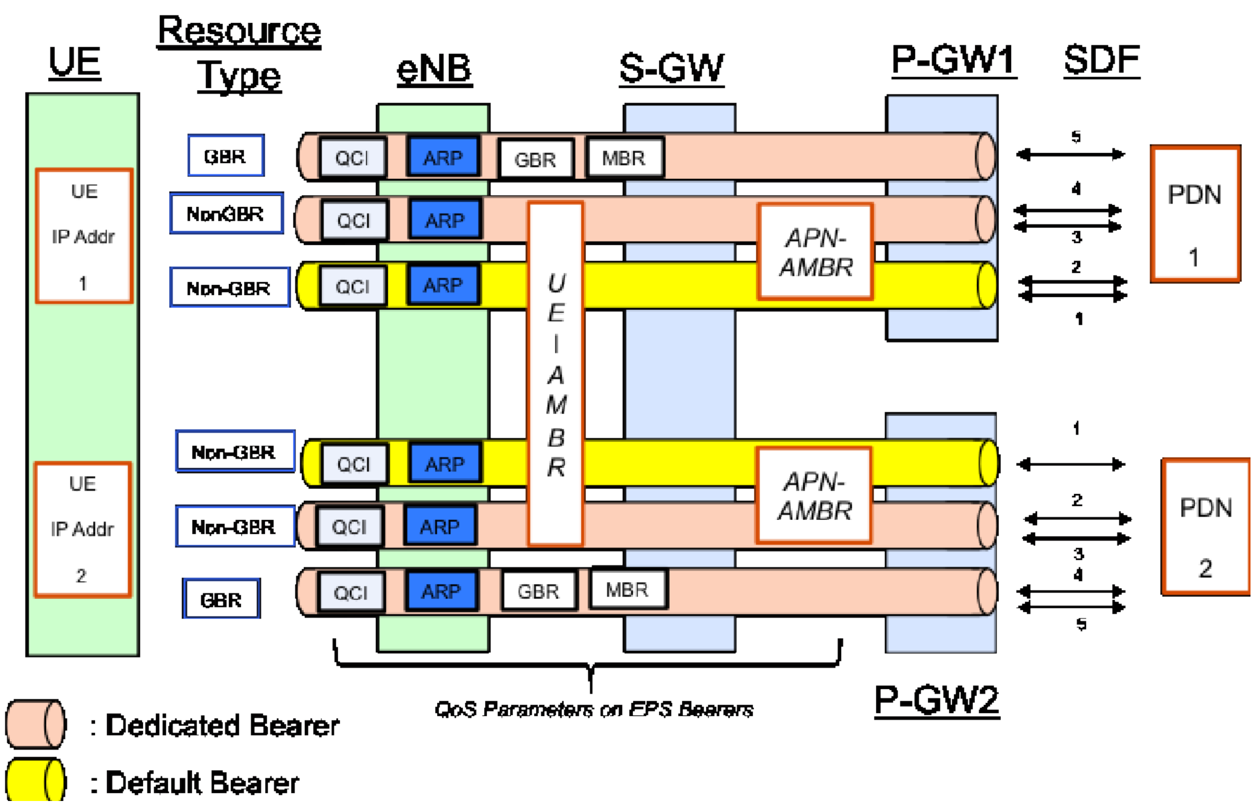

Figure C5 : LTE EPS QoS Parameters

Rate limiting is implemented using AMBR (Uplink/Downlink) for non-GBR bearers (e.g., default bearers). An EPS bearer having a non-GBR resource type does not reserve resources so the resulting connection is best effort. That is, the total bandwidth of all the non-GBR EPS bearers in a PDN is limited, but not the individual bandwidth of each bearer. The Access Point Name Aggregate Maximum Bit Rate (APN-AMBR) sets the limit for all of the UE bearers related to a specific LTE access point (i.e., all non-GBR bandwidth used for a particular IP network). Another rate limiting control for non-GBR bearers is the UE aggregate maximum bitrate (UE-AMBR). Note that a UE can be connected to more than one PDN (e.g., PDN 1 for Internet, PDN 2 for Voice over Internet Protocol (VoIP) using IMS), and it has one unique IP address for each of its PDN connections. This rate limiting control (UE-AMBR limiting) is enforced across all non-GBR LTE bearers that are associated with a UE, independent of the bearer's termination point (APN). The LTE network will allow rates up to the value of the UE-AMBR for a UE.

The following bandwidth management parameters, GBR and MBR, are applied for GBR type EPS bearers. A GBR bearer is established "on-demand" because it blocks the resources by reserving them during admission control. For each LTE (GBR-type) bearer admitted to the LTE system, the GBR value is the minimum bandwidth provided by 700MHz NPSBN. The admission process allocates enough bandwidth to assure delivery of data up to the value of the GBR. This bandwidth is available to the UE independent of the NPSBN congestion levels. The MBR is the absolute maximum amount of bandwidth an LTE GBR bearer can utilize once it has been admitted. The MBR allows for additional bandwidth utilization above the GBR value assuming there are resources available in the NPSBN.

The combination of the rate limiting and bandwidth management parameters described above provides flexibility in allocation of bandwidth on the LTE network. These controls can be set by the authorized agency administrator to meet the required needs of the responders who are utilizing bandwidth on the NPSBN.

Priority and QoS (PQoS) Control Service Framework [3][11]

The NPSBN LTE network provides standardized mechanisms to enforce public safety's desired Access Control, QoS and ARP (priority and preemption policies) as mentioned above.

The draft PQoS report, developed by NPSTC and shared with FirstNet [3], has proposed to track more priority and QoS user attributes. It includes real time factors (e.g., user's operational status, incident role and any declaration of an emergency or immediate peril) that influence a user's priority, such as new types of dynamic (or situational) priority, as described in Section 4.3.4. The PQoS framework [3] calls these user attributes 'U1" through "U10" (Figure **C6**). Notice that some user attributes are available today and others are not. PQoS collects and analyzes these user attributes to calculate a priority value (Figure **C7**) that would be assigned to a user or application. These user attributes include static (default) attributes assigned at the time the UE is provisioned and dynamic (situational) attributes that change based on the user's assignment.

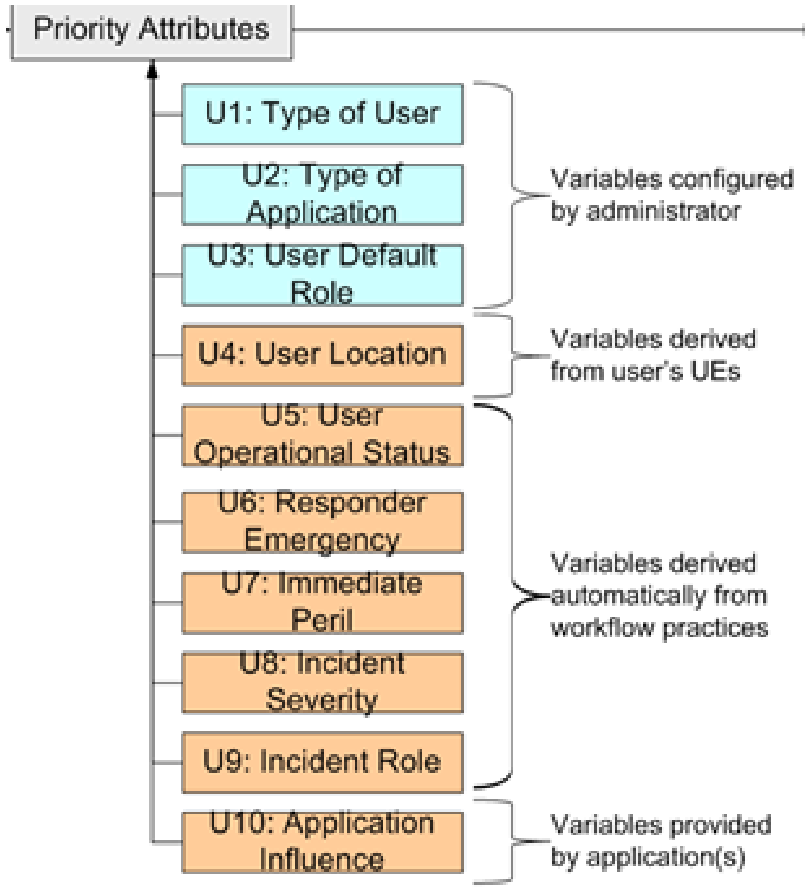

Figure C6 : PQoS Static and Dynamic Attributes [3]

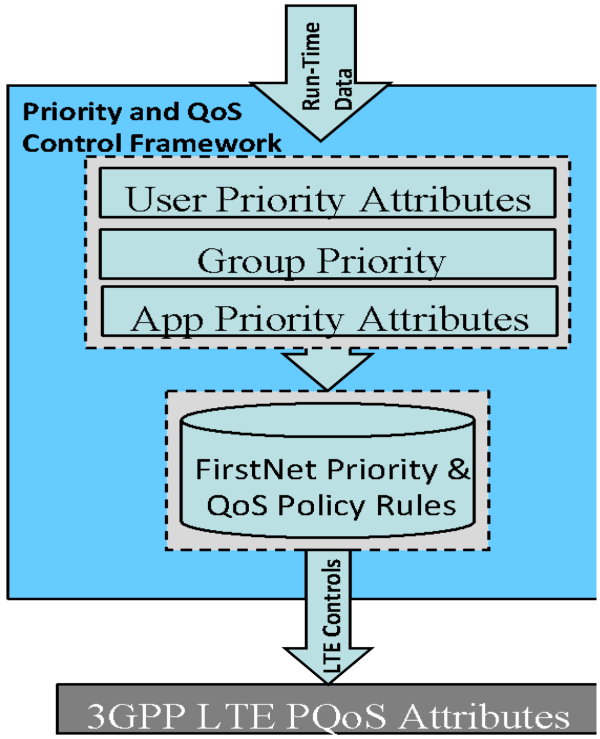

Figure C7 : PQoS Framework [3]

LTE FEATURES FOR OFFLOADING AND DYNAMIC ALLOCATION

While minimizing the content size and prioritizing traffic will help to utilize the resource limited LTE network efficiently, other methods must be considered to provide additional coverage and capacity to further congestion management.

To reduce possible NPSBN congestion issues, certain features (e.g., dynamically offloading traffic, Enhanced Multimedia Broadcast Multicast Service (eMBMS), and increasing network coverage and capacity) may be employed. Some of these features are currently available and others need additional developmental work in the LTE standards organization. This section briefly discusses the main features and further advancements for future LTE network.

Proximity-Based Services (ProSe) – Device-to-Device (D2D) Communications

The ProSe feature is defined in the 3GPP Standards [12] and detailed in several 3GPP technical reports [13][14]. It is also referred to as D2D communication, and is being developed in LTE Release 12. It is for both public safety and commercial users. Figure **C8** depicts ProSe direct communication scenarios (i.e., without a relay) [13]. D2D communication would allow

NPSBN traffic offloading when UEs are in proximity and consuming significant bandwidth, such as sharing video. Hence, this feature effectively increases capacity in given bandwidth and reduces network load. Furthermore, this feature is essential for public safety users in case of absence of E-UTRAN coverage (the network is down due to natural disaster) or outside of coverage range (through ProSe UE-to-UE relay [14]).

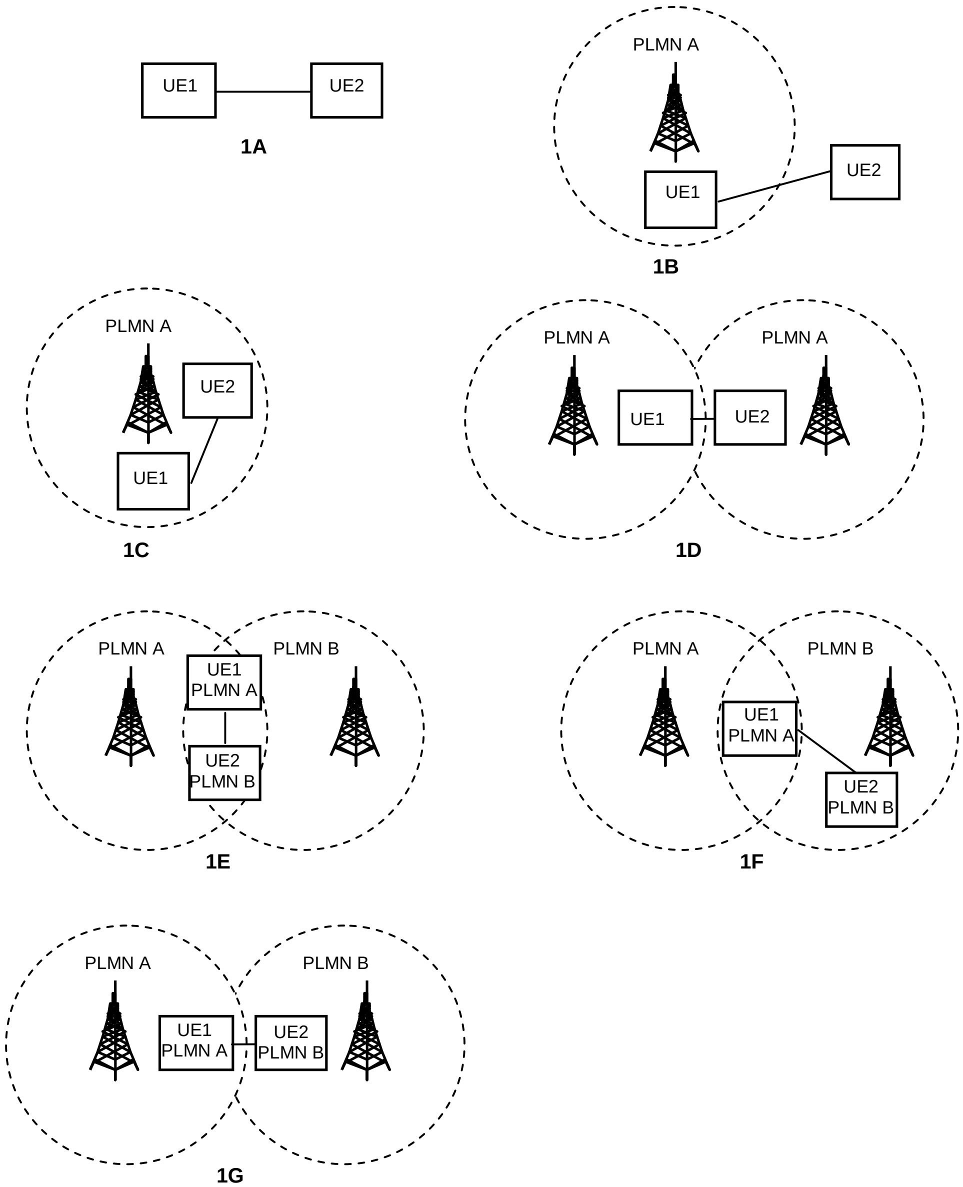

Figure C8 : ProSe Direct Communication Scenarios Without a Relay [13]

Two different modes for ProSe direct communication are supported:

1) Network independent direct communication (Figure **C8**, case 1A): This mode of operation for ProSe direct communication does not require any network assistance to authorize the connection. Communication is performed by using only functionality and information local to the UE(s). This mode is applicable to both ProSe direct communication one-to-one and ProSe direct communication one-to-many, regardless of whether the UEs are served by E-UTRAN or not.

2) Network authorized direct communication (Figure **C9**): This mode of operation for ProSe direct communication always requires network assistance by the EPC to authorize the connection. Note that this mode of operation may apply when only one UE is served by eNB.

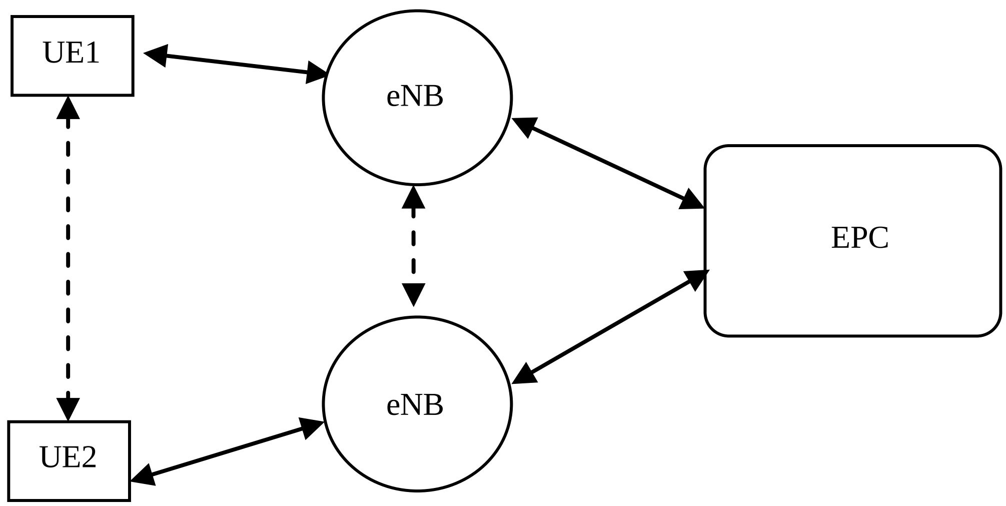

Figure C9 : Example for Network-Supported ProSe Communication for UEs Served By Different eNBs [14]

Group Communication System Enabler for LTE (GCSE_LTE) [15]

To position LTE as a technology meeting NPSBN requirements specified in the *Recommended Minimum Technical Requirements* document [4], the Public Safety Broadband High-Level Launch Requirements [5], and the Public Safety Broadband Push-to-Talk Over Long Term Evolution Requirements [16], a so-called "group call" is needed. The Group Communication System Enablers for LTE (GCSE_LTE) feature is simply such a group call being developed in LTE Release 12. It provides dynamic groups with mobile users and dispatchers, and supports a one-to-many communication (e.g., push-to-talk requirements [16]) for LTE voice, video and data. GCSE_LTE is a feature that complements ProSe. When one or more UEs are outside LTE coverage, but in proximity to another UE in the same group, the GCSE_LTE feature allows the group call to these UEs through ProSe UE-to-Network Relay feature. The logical Venn diagram in Figure **C10** shows the concept of a group communications with three characteristics: a member of a group A, the UE being reachable (R group), and the UE wanting to participate the group (P group).

The GCSE_LTE work is divided into Radio Access Network (RAN), Core Network and Application layer functionality for group communication. The RAN layer will transmit media to devices in the most resource efficient way, along with applicable parameters (e.g., QoS, priority), either point-to-point or point-to-multipoint. The Application layer functionality establishes and controls group membership and floor control/arbitration. The Core Network connects the media from the sender to the RAN node for distribution to the group members. Only members of the group are allowed to receive or transmit to that group. Like controlling use of resources for non-group communication traffic, NPSBN network shall configure each GCSE group's priority level and shall preempt lower priority GCSE groups for more critical (group) communication.

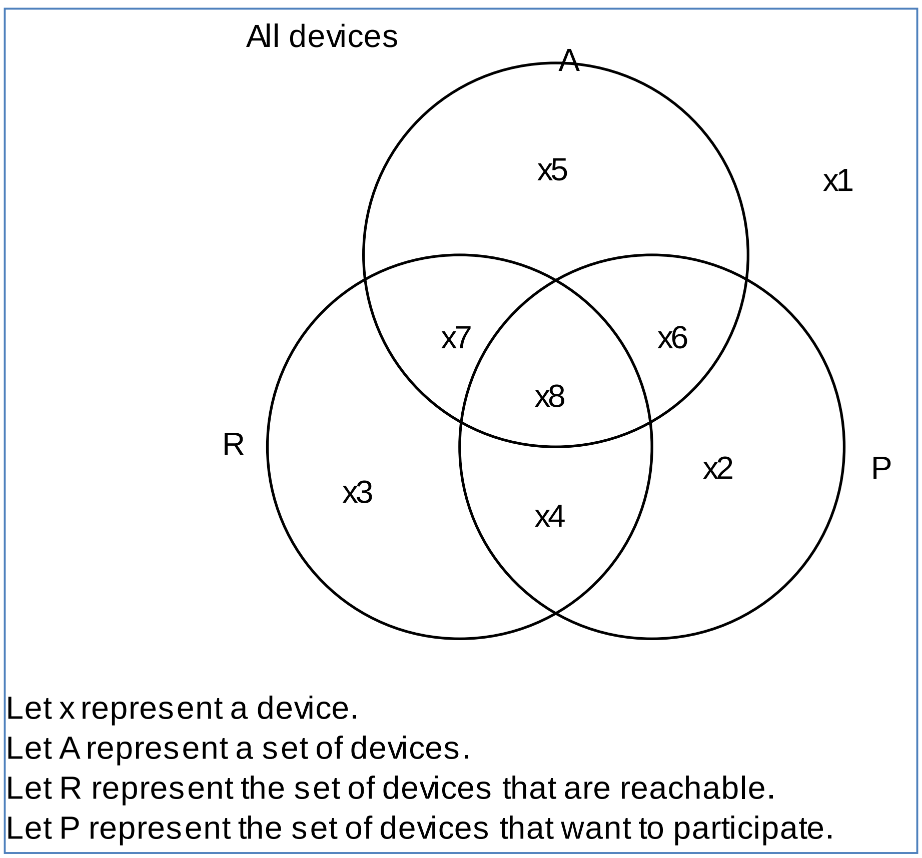

Figure C10: Group Characteristics [15]

Offloading Traffic to Commercial LTE Networks

It is well known that allowing public safety users to access shared commercial LTE networks can yield significant advantages, including increasing the aggregate capacity, coverage and reliability beyond what's possible with NPSBN alone. Studies[13] published at the 2011 Telecom World Technical Symposium [17] and in Homeland Security Affairs, the Journal of the NPS Center for Homeland Defense and Security [18], have quantified these advantages and how the priority mechanisms in commercial LTE network are mapped to NPSBN requirements, in terms of guaranteeing the radio access admission and EPC bearer assignment based on QoS and ARP priority.

A representative scenario for offloading traffic to commercial LTE networks is summarized in Figure **C11**. The NPSBN traffic is initially supported in NPSBN RAN at band 14. During emergency congestion, the NPSBN user is handed over to the shared commercial RAN operation. If the commercial RAN is also congested, the new NPSBN user is assigned resources in the NPSBN RAN by invoking the proper priority mechanisms (e.g., preempting a lower priority user).

[13] These studies also indicate that the level of interest from commercial carriers will depend on the financial terms in the arrangement with NPSBN (i.e., FirstNet), as well as technical terms (e.g., cannot seriously compromise QoS for their commercial customers).

<table>
<tr><th colspan="2" rowspan="2">Radio Network Condition</th><th colspan="2">Shared Commercial Bandwidth Utilization</th></tr>
<tr><th>Below Capacity</th><th>At Capacity</th></tr>
<tr><td rowspan="2">Dedicated {NPSBN) bandwidth utilization</td><td>Below Capacity</td><td>Uses NPSBN Spectrum</td><td>Uses NPSBN Spectrum</td></tr>
<tr><td>At Capacity</td><td>Handed over to shared commercial network</td><td>NPSBN uses priority method</td></tr>
</table>

Figure C11: NPSBN User Operation [17]

Other important issues are still to be determined. For example, knowing how to balance the aggregate capacity usage in the shared commercial RAN between public safety users and commercial users is needed because the public safety user can invoke priority treatment even in its normal operation. These kinds of technical issues need to be addressed in the arrangement between NPSBN and commercial carriers.

Self-Organizing Networks

The Self-Organizing Networks (SON) technique, as described in various 3GPP Technical Standards and Reports [19][20][21][22], is fundamentally changing the way LTE networks are deployed and operated because it will automate many tasks that previously had to be performed manually. The concept of SON was introduced in Release 8 with a focus towards eNB self-configuration. In Release 9, requirements for self-optimization were added. In Release 10, enhancements to SON features previously introduced in earlier releases were made, including self-healing procedures.

The aim of self-configuration functionality of SON is for new base stations to become essentially “plug and play” elements. A technique called dynamic radio configuration is used to set adaptively the basic configuration radio parameters in current radio network topology, while automatic neighbor relation management identifies the neighbor base stations and establishes neighbor relationship. Once the base station has been configured, it is necessary for the self-optimization functionality of SON to continuously optimize and fine-tune the operational characteristics (e.g., adjust neighbor cell list or handover parameters) to best meet the requirements of the overall network. The self-optimization functionalities can focus on one of the following:

- Mobility robustness optimization: to minimize the drop calls, radio link failures, or unnecessary handovers;
- Mobility load balance and traffic offload: to reduce “data hotspots” and to offload for example, the (low mobility) traffic from macro cells to the smaller cells;
- Coverage and Capacity Optimization: adjusting power level and antenna parameters to maximize coverage while optimizing the capacity by ensuring the inter-cell interference levels are minimized; and
- Random Access Channel optimization: to accurately devote the resource to enable random access (while not sacrificing network performance and valuable resources) through handset reporting and inter base station data exchange.

Figure **C12** shows the logic view of the self-optimization procedure. After analyzing the input data (e.g., measurements from UE and eNB) to the self-optimization, the decisions will be made according to the optimization algorithms. The corrective actions on the affected eNB will be triggered and executed automatically. The enhancement of self-healing functionality of SON tries to detect and correct faults (e.g., cell outages in the network) automatically.

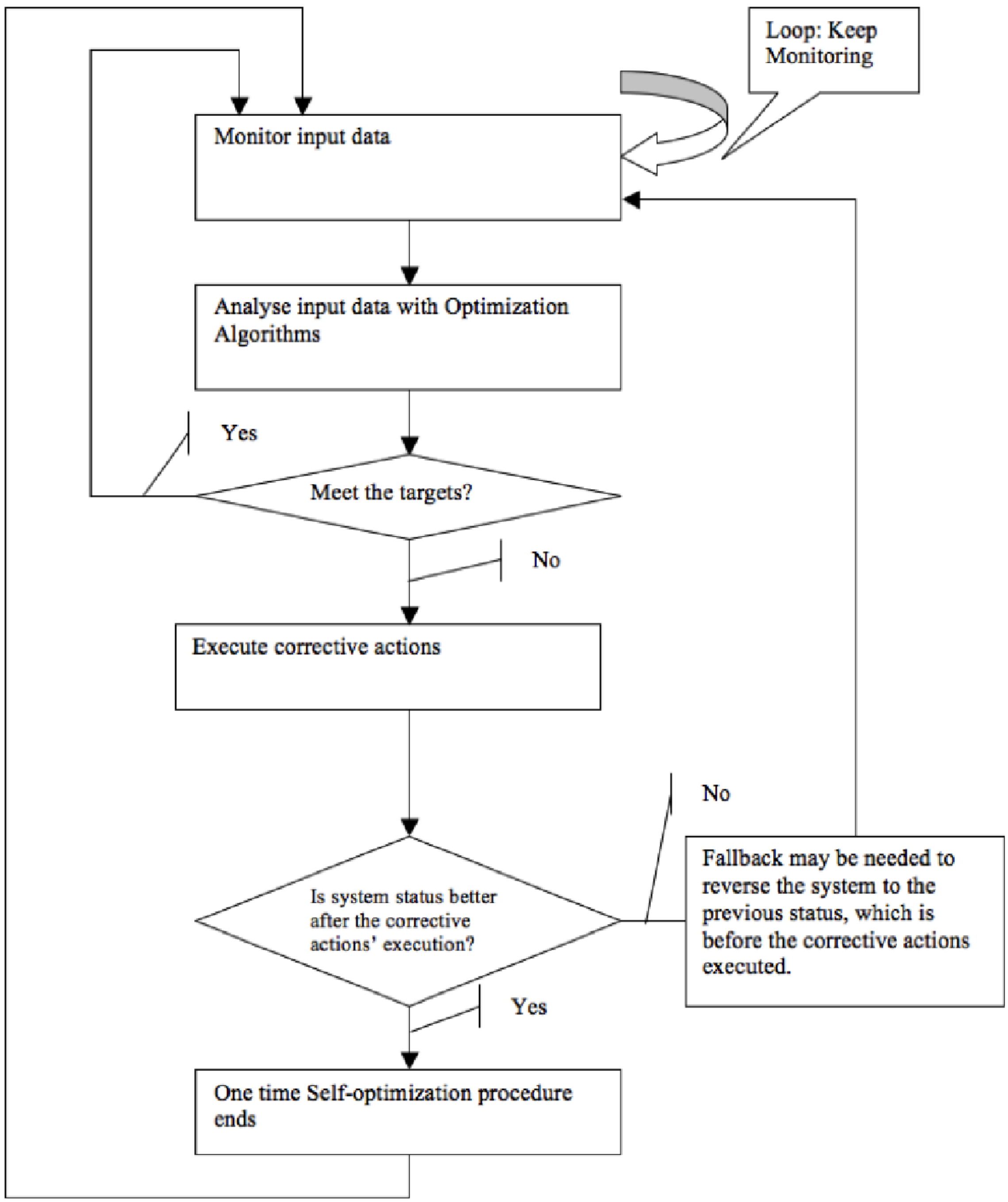

Figure C12: Logical View of self-optimization procedure [22]

During a major public safety incident, network congestion is likely occurring in NPSBN. The congestion will impact public safety UE's ability to access NPSBN network. Besides the LTE policy and priority mechanisms to manage the congestion, one effective solution is to deploy low-power eNBs equipped with SON near the major public safety incident area to establish small cell(s). These deployable eNBs can greatly increase network coverage and capacity. Additionally, SON with the enhanced features mentioned above will help to operate the LTE network efficiently by constantly monitoring network data such as performance measurements and network conditions, and automatically make the appropriate corrective actions according to the optimization algorithms.

Offloading Traffic in Heterogeneous Networks

The 3GPP has been working to further advance the performance of LTE networks, including various aspects such as higher order multiple input multiple output, carrier aggregation (CA), and heterogeneous networks (HetNet) [25][26]. Currently the spectral efficiency per link is already approaching theoretical limits with LTE. Further advancement will have to be obtained from advanced radio network topology. HetNet, utilizing the combination of large macro cells with small cells and including deployable cells during an emergency situation, can be used to improve the spectral efficiency per unit area. Typically, the placement of macro base stations in LTE networks is based on careful network planning. However, the placement of small cell base stations (e.g., pico, relay and deployable base stations) may be more or less ad hoc, based on coverage concerns, traffic congestion or emergency situations in the network. Smarter resource coordination among various base stations (e.g., using the SON technique) and more advanced techniques for efficient interference management [27] (e.g., enhanced inter-cell interference coordination for small cell enhancement) can provide substantial gains in throughput, coverage and user experience as compared to a conventional Release 8 approach.

CA [25] originally specified a cost effective way for operators to utilize their fragmented spectrum across different or the same bands to improve UE maximum throughput. User throughput is incremented by sending data simultaneously over two or more, contiguous or non-contiguous carriers. CA can work in HetNet through inter-site carrier aggregation between macro and small cells, which results in dual connectivity. It results in both throughput gain and resiliency. In addition to traffic offloading to commercial network strategy, CA between the NPSBN band and other bands can be applied during the NPSBN congestion period. Figure **C13** shows examples of CA applied to HetNet deployments, where macro UE can apply intra-site CA, or inter-site CA for macro and pico UE.

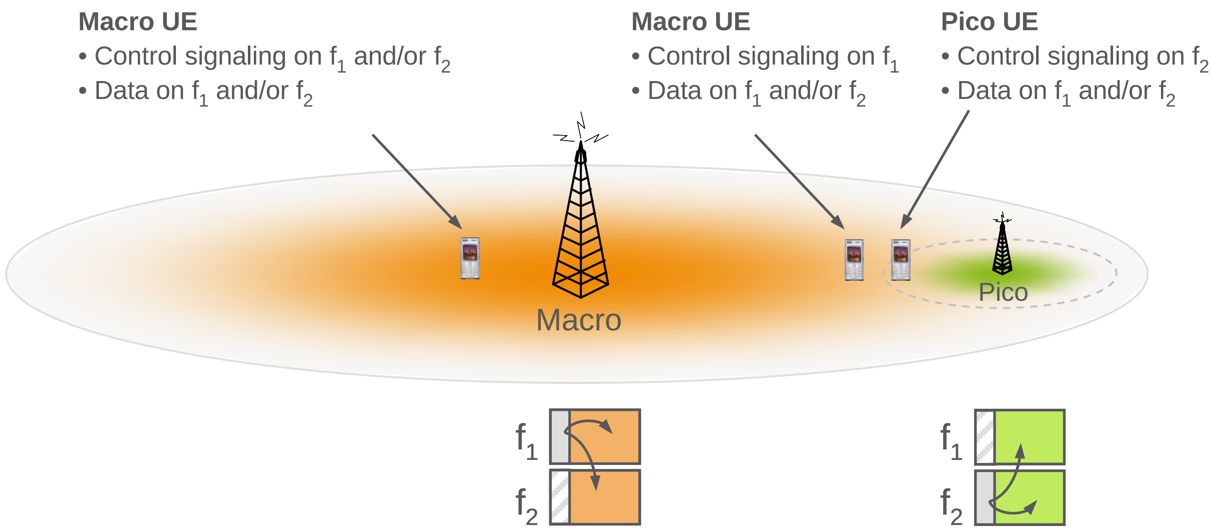

Figure C13: Examples of CA applying to HetNet Deployments [25]

eMBMS

As described in various 3GPP technical standards and publications [28][29][30], eMBMS is a point-to-multipoint service in which data are transmitted from a single source entity to multiple recipients. It reuses existing LTE spectrum flexibly and efficiently by offloading capacity from unicast to multicast for delivery of common content to a large number of UEs when and where needed. eMBMS in LTE makes it possible to broadcast data over a single frequency network (SFN). All cells belonging to a multicast-broadcast single-frequency network (MBSFN) area are coordinated for MBSFN transmission. Transmitting the same data in a time-synchronized manner to multiple recipients in a MBSFN area allows network resources to be shared. Providing very popular services (e.g., video stream of a sporting event) or video for first responders in a major public safety event as eMBMS services can greatly reduce the cost for the NPSBN network. In addition, given NPSBN deployment with limited resources, eMBMS may be one way to provide data service efficiently to public safety end users.

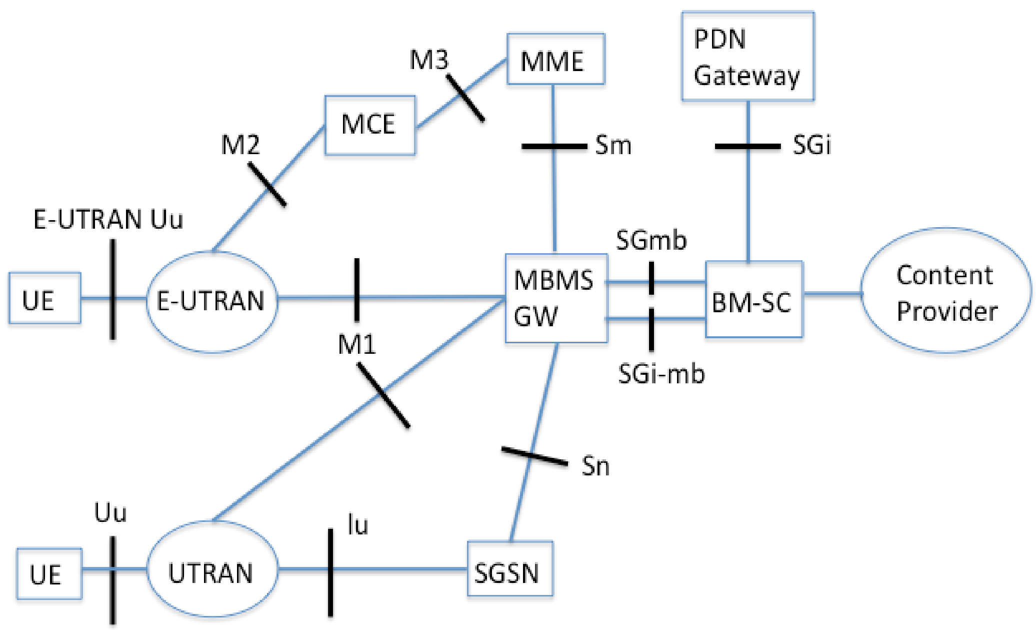

Figure C14 : eMBMS Reference architecture for EPS with E-UTRAN and UTRAN [30]

The eMBMS logical architecture with new logical network entities is shown in Figure C14. The broadcast multicast service center (BM-SC) acts as a proxy content server and is responsible for authentication, content authorization, billing and configuration of the data flow in the core network. In the EPS, a new functional entity MBMS gateway (MBMS GW) exists at the edge between the core network and the BM-SC. MBMS user data is delivered by the MBMS GW to each eNB. The Multi-cell Coordination Entity (MCE) handles admission control and decides on allocation of resources used by all eNBs in the MBSFN area. The MCE acts as a de facto MBMS scheduler. New interfaces M1 to M3 are defined between the entities as shown in Figure C14.

Configuration of the MBMS services and related channels is performed at the higher layers. The new SystemInformationBlockType13 contains the information required to acquire the MBMS control information associated with one or more MBSFN areas. MBMS user data is carried by the logical multicast traffic channel (MTCH), which is mapped onto the multicast channel (MCH) as a transport channel. For providing control and scheduling information about the MBMS services to the UEs, the logical multicast control channel (MCCH) is used, which is also mapped onto the MCH and can be multiplexed with the MTCH. The UEs are notified about the changes in MCCH information.

Datacasting

JHU/APL is currently working to develop test beds for datacasting under the DHS S&T First Responders Group Resilient Systems for Public Safety Communications task. Datacasting enables the broadcast of encrypted data using digital television signals. The encrypted information is multiplexed into the television signal and transmitted to authorized end users who have the capability to decode the transmitted data. This is a broadcast technology where many can receive data from a single source (i.e., a one-to-many communication scheme). By offloading video services to the datacasting network, resource requirements for video service can be reduced on the NPSBN LTE network.

Although similar to eMBMS with respect to the multicast/broadcast approach, datacasting and LTE are currently incompatible from a system integration standpoint. To utilize datacasting to offload traffic from the LTE network, the LTE device must have the capability to utilize both technologies. Similar to the GSM ANSI-136 Interoperability Team (GAIT) standardization work [31] (which allowed GSM, TDMA and analog AMPS networks to interoperate seamlessly using a GAIT phone), the appropriate standards need to be developed to allow seamless interoperability between LTE and datacasting networks and UEs.

REFERENCES APPENDIX C

[1] Middle Class Tax Relief and Job Creation Act of 2012, PUBLIC LAW 112-96, enacted 22 February 22 2012

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APPENDIX D LIST OF ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AC	Access Class
ACB	Access Class Barring
AMBR	Aggregate Maximum Bit Rate
AMPS	Advanced Mobile Phone Service
APN	Access Point Name
ARP	Allocation and Retention Priority
BM-SC	Broadcast-Multicast Service Center
CA	Carrier Aggregation
D2D	Device-to-Device Communication
E-UTRAN	Evolved Universal Terrestrial Radio Network
eMBMS	Enhanced Multimedia Broadcast Multicast Service
eNB	evolved Node B (the LTE system base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
FirstNet	First Responder Network Authority
GAIT	GSM ANSI-136 Interoperability Team
GBR	Guaranteed Bit Rate
GSM	Global Systems for Mobile communications
GW	Gateway
HetNet	Heterogeneous Network
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IP	Internet Protocol
MBMS	Multimedia Broadcast Multicast Service
MBR	Minimum Bit Rate
MBSFN	Multicast-Broadcast Single Frequency Network
MCCH	Multicast Control Channel
MCE	Multi-cell Coordination Entity
MCH	Multicast Channel
MME	Mobility Management Entity
MTC	Machine Type Communications
MTCH	Multicast Traffic Channel
NPSBN	National Public Safety Broadband Network
PCEF	Policy Control Enforcement Function
PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
PQoS	Priority, Pre-emption, and Quality of Service
ProSe	Proximity-based Services

3GPP	3rd Generation Partnership Project
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RB	Radio Bearer
SDF	Service Data Flow
SFN	Single-Frequency Network
SON	Self-Organizing Network
UE	User Equipment
USIM	Universal Subscriber Identity Module