Advanced Communications Video Over LTE: Video Design Improvement Process

First Responders Group

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TABLE OF CONTENTS

1 PROBLEM STATEMENT

The Department of Homeland Security (DHS) sponsored Video Quality in Public Safety (VQiPS) Working Group (WG) seeks to determine the most efficient means to provide the video data needed by the public safety community without compromising public safety or degrading wireless bandwidth unnecessarily. There are important trade-offs to be considered when sending video over a wireless network. High definition video may overwhelm the wireless network's bandwidth, but the highest quality video is likely not necessary for every public safety situation. The National Public Safety Telecommunications Council (NPSTC) *Public Safety Communications Assessment* [1] proposed three generic terms for different video quality levels (low, medium and high) to meet the goal of providing the video data needed for a situation without compromising the wireless bandwidth needed for other communications. However, these three terms have not been sufficiently quantified in light of research efforts. To provide the First Responder Network Authority (FirstNet) with quantifiable guidelines for broadband/LTE video transmission, there is a need to extend these generic video quality requirements.

This report presents the relevant background on the wireless video transport design requirements, and uses these requirements to identify parameters affecting video quality and bandwidth requirements for the designated video quality levels. This information is necessary to achieve the goal of providing first responders with the video quality they need while working to maintain sufficient wireless bandwidth capacity. *This report seeks to educate public safety users, video content owners and wireless carriers about the variables that affect video content and transport of this video with the quality necessary to meet their mission*. The information in this document is derived from earlier research by the Public Safety Communications Research (PSCR) program (see http://www.pscr.gov/projects/video_quality/) and attempts to extend its applicability to the wireless transport of video. A general process for extending applicability to wireless transport is described based on this earlier research, but more recent technological advances in cameras, video compression and video processing may need to be considered. Therefore, recommendations are made for future areas for study.

2 BACKGROUND

First Responder Network Authority

The U.S. Congress passed the Middle Class Tax Relief and Job Creation Act [2] in February 2012. This Act created FirstNet, an independent authority within the U.S. Department of Commerce's National Telecommunications and Information Administration (NTIA). The mission of FirstNet is to build, operate and maintain the first high-speed nationwide wireless broadband network dedicated to public safety. This network, known as the Nationwide Public Safety Broadband Network (NPSBN), is based on the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) wireless standard [3].

Video Quality in Public Safety Working Group

The DHS Science and Technology Directorate (S&T) is responsible for leveraging the engineering and technological assets of the United States to organize these assets and conduct research into technology-based tools to protect the homeland. DHS S&T's First Responders Group (FRG) / Office for Interoperability and Compatibility (OIC) administers a program entitled *Video Quality in Public Safety* (VQiPS), which addresses the use of video in public safety applications.

Closed Circuit Television (CCTV) and other video systems have been increasingly adopted for use in various settings involving different governmental departments and agencies. The first responder community relies on these video systems for situational awareness across a wide range of emergency response situations. As a result, increased attention to issues related to video quality and wireless video transmission is required.

In 2008, the VQiPS WG was formed from a partnership between DHS OIC and the U.S. Department of Commerce PSCR program. The VQiPS WG was created to improve the way video technologies serve the public safety community, and is comprised of public safety practitioners, federal agencies, academia, manufacturers and representatives of standards-making bodies. The VQiPS WG took an innovative approach to defining video quality requirements by: surveying existing video quality standards and specifications being developed for all public safety applications; creating a framework for specifying applications requirements in generalized terms common to all or most applications; creating a guide for public safety agencies to help map these generalized requirements to existing specifications and standards; and determining areas where further research is needed.

The VQiPS WG also seeks to help reduce any duplication of effort by providing a forum for discussion and education on current and future solutions. Additional information about the VQiPS WG can be found on the PSCR website: http://www.pscr.gov/outreach/video/vqips/ .

3 PSCR VQIPS VIDEO USE CLASSES, COMPONENTS AND REQUIREMENTS OVERVIEW

In March 2013, the VQiPS WG issued the document *Defining Video Quality Requirements: A Guide for Public Safety* [4], as well as other resources on the PSCR VQiPS website [5][6][7]. These resources were designed to help the public safety and emergency responder community understand the impact of video system components on video quality and to provide a general guideline with attributes to consider when selecting a video system.

The VQiPS WG describes video quality as "the ability of the emergency response agency to use the required video to perform the purpose intended." The required video quality must enable the viewer to successfully recognize a specific element of interest within an incident scene at a certain discrimination level, to be described later in this section.

The following sections will describe the establishment of generalized classes of use cases, core video system components and the VQiPS Recommendations Tool for Video Requirements. These sections summarize PSCR's previous work and how the Johns Hopkins University Applied Physics Laboratory (JHU/APL) has extended this work to the assessment of the wireless transmission of video. The relevant references and resources can be found in the VQIPS guideline [4] and on the PSCR VQiPS website [7].

3.1 GENERALIZED USE CLASSES

The NPSTC developed a set of use cases contained in the *Use Cases & Requirements for Public Safety Multimedia Emergency Services* document [8], with direct feedback from the members of the public safety community. The use cases were developed to identify communication needs of the first responder by using scenarios involving multi-media content, including text, pictures, audio, etc. This new suite of media-rich services is referred to as the Multimedia Emergency Services (MMES). A derivative of these use cases will be examined in Section 6 of this report.

The end user's mission-level requirements for video can be quantified within the context of the incident scene through the development of use cases. For example, low quality video may be sufficient for a command center monitoring general crowd movement during a concert, while high quality video may be needed for facial recognition during a hostage situation. Each scenario is different, but the intended purpose (i.e., mission) of the video can be associated with the level of video quality needed to meet the requirements for that use case.

Because there are so many different departments and agencies within the local, state, tribal and federal levels of government, the number of possible use case scenarios is almost without limit. In order to reduce this complexity, the PSCR established a use case independent (or neutral) framework to facilitate the development of video quality requirements [9]. The basic concept behind this schema is that use cases from different disciplines (e.g., fire, police, emergency medical services) have similar video quality requirements and thus there are underlying use case aspects commonly shared by all. For example, an automatic motor vehicle license plate reader used by law enforcement is different from an Emergency Medical Services (EMS) video application, but the mission requirement for high quality video may be the same.

The PSCR determined that the following five aspects were common to various use cases having an impact on the video quality: discrimination level, usage time frame, target size, motion and lighting level. As shown in Figure 1, the combination of these use case aspects forms a Generalized Use Class (GUC) [10]. Different factors within the use case aspects determine the perceived video quality and therefore the usability of the video for a particular task.

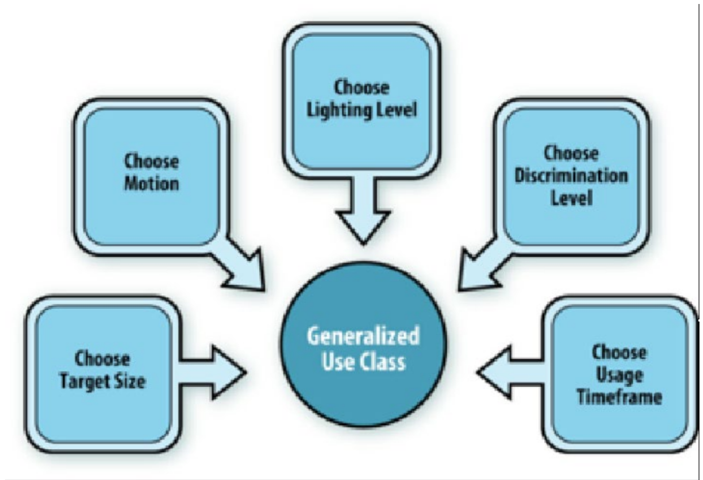

Figure 1 Generalized Use Class (GUC)

Figure 2 was compiled with information obtained from the *Defining Video Quality Requirements: A Guide for Public Safety* document [4] and the VQiPS website [7]. It summarizes the GUC aspects in terms of their characteristics, which are described in more detail. For example, Discrimination Level describes the level of detail needed for a specific task or the intended purpose of the video. This ranges from "positive recognition" to "high-level description of actions." The former requires a higher level of video quality, while lower quality video is sufficient for the latter.

GUC ASPECTS	CHARACTERISTICS	EXPLANATION
Discrimination Level	Target Positive ID	Enough detail to make positive recognition, such as a face, an object, or alpha-numeric characters
	Target Class Characteristics	Medium-scale detail recognition, such as gender, markings, smaller actions
	Target Class Recognition	Large-scale recognition, such as a car versus a van
	General Elements of the Action	High-level description of actions that took place, such as of people, a person, or a vehicle
Usage Time Frame	Live or real-time	The video is being viewed at the same time it is being shot
	Recorded	The video will be saved and capable of being played back
Target Size	Large	The target occupies a large percentage of the frame
	Small	The target occupies a smaller percentage of the frame
Motion	High	There is a lot of motion or edges in the video
	Minimal	Low complexity, there is not much motion, or many edges
Lighting Leve	Constant Lighting - Bright	Lighting is at a comparatively bright level
	Constant Lighting - Dim	Lighting is at a comparatively dim level
	Variable Lighting	Lighting ranges from bright to dim

*Source Video Quality in Public Safety, http://www.pscr.gov/projects/video_quality/vqips/

Figure 2 GUC Description, Derived from *Defining Video Quality Requirements* guide [4]

3.2 CORE VIDEO SYSTEM COMPONENTS

From the *Defining Video Quality Requirements* guide [4] and the PSCR VQiPS website [5][6][7], a generic video system is composed of the functional blocks illustrated in Figure 3. These blocks identify 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 an end user's display. Video quality can be negatively impacted at each step, which may result in the inability of the end-user to utilize the video for its intended purpose.

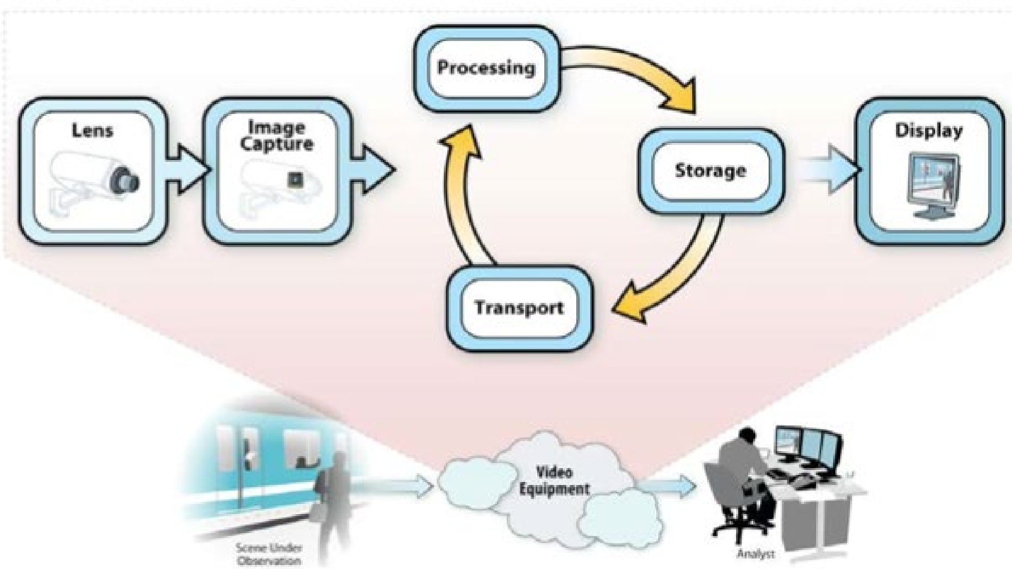

Figure 3 Video System Reference Model

The Lens and Image Capture components of the video system reference model are intrinsically important. The remaining video system components cannot improve video quality beyond the limits imposed by the quality of these lens and image capture components.

The following sections, 3.2.1 to 3.2.6, are quoted directly from the *Defining Video Quality Requirements* [4] guide and are presented here to serve as a quick reference. These sections describe each component in the video system reference model and possible attributes that may have an impact on video quality. They serve to highlight the fact that, as the video image progresses through the video system, each component can potentially decrease the quality of the video. The balance between end user video quality requirements and requirements of the video system components needs to be well managed. When designing the video system, it is also necessary to take into consideration the video quality requirements of the mission, as well as video quality versus file size and transport network limitations.

3.2.1 LENS CONFIGURATION

Description: The optical component of a camera system is a lens or series of lenses used to create an image on some sort of media, such as photographic film or electronic means. A lens can be a simple convex surface or composed of a number of optical elements in order to correct the many optical aberrations that arise. A lens may be permanently fixed to a camera or may be interchangeable with lenses of different focal lengths, apertures and other properties.

<u>Attributes that might affect video quality</u>

- Lens Aberration – Lenses do not form perfect images; there is always some degree of distortion or aberration introduced by the lens that causes the image to be an imperfect replica of the object.
- Field of View – The extent of the observable world that is seen at any given moment through the lens.
- Focal Length – Determines the field of view and the apparent size of the objects relative to the image size.
- Aperture – Refers to a lens opening to reduce or increase the amount of light that reaches the image capture surface. The aperture controls the brightness of the image and the fastest shutter speed usable.
- Depth of Field – The range of distances that appear acceptably sharp in the image.

3.2.2 IMAGE CAPTURE

Image capture is the process of recording data, such as an image or video sequence.

Description: The image capture process consists of converting the information (i.e., light) from a real scene into a stream of information that is suitable for the remaining links via a photographic or electronic medium.

In the case of modern video, the process is modified slightly. The camera is in front of a scene and it has optics (usually just a lens, but it could be a night vision system). The lens presents focused light to the internal workings of the camera—a projection of the information from the scene. The camera converts the projected information into a stream of electronic data that can support subsequent processing, storage and viewing. For digital images, the capture process converts light into a digital form via a sensor and digitization.

<u>Attributes that might affect video quality</u>

- Resolution at which the camera captures information.
- Frame rate at which the camera captures information.
- Fidelity of the colors captured.
- Dynamic range of the recording medium.
- Number of bits per pixel (digital cameras) Noise (analog cameras).
- Infrared capability of image capture system.

3.2.3 PROCESSING

Description: Processing refers to any enhancement, restoration, or other operation that is performed on a video signal. This could also refer to any processing that occurs automatically as part of a system; for example, the processing performed inside a digital camera to convert an image into an image file format. The three main file formats for digital photographs are RAW, TIFF and JPEG.

<u>Attributes that might affect video quality</u>

- Compression – Also referred to as coding, compression involves electronically processing a digital video picture so that it uses less storage and allows more video to be sent through a transmission channel. Most methods for compression result in a loss of fidelity that is not recoverable. Compression can be used to reduce the amount of bandwidth needed to transmit a video. A user must use a decoder to view a file that has been compressed (or encoded) or else the video cannot be viewed. There are open source video encoder/decoders that exist on the market; however, there are many proprietary systems that require their own specific decoder.
- Digitization – Converting an analog video source to a digital format.
- Enhancement for Analysis – Many methods are available to increase clarity for certain parts of the video. Examples are frame averaging, edge enhancement and color balancing.
- Delay – Video images can be delayed, which can result in incomplete or inaccurate real-time decision-making.

3.2.4 TRANSPORT

Transport refers to the effects of moving or copying from one location to another.

Description: Transport and network are terms that go hand-in-hand, depending on the Information Technology Engineer's preference. This document will refer to this concept as transport. The transport can be wired (including fiber optics), wireless or any combination of these. The distance of the transport can range from a few feet within a building to the other side of the world. The transport has unpredictable effects on the transmission of the electrical signal between two or more electronic devices.

<u>Attributes that might affect video quality</u>

- Available Bandwidth – The amount of data a network is able to carry affects the speed and size of the video signal that is able to reach the destination.
- Network Sharing – Other users on the network may reduce the available bandwidth.
- Loss of Data (digital) – When digital information is transmitted, it is broken into short blocks of data called "packets." Packets are sent separately and then reassembled on the receiving end of the system. For many reasons, some packets are lost in transmission, causing a loss of some pieces of the video picture.
- Loss of Data (analog) – Noise can interfere with an analog signal (e.g., "snow" on analog TV), permanently obscuring portions of the video field.
- Delay – Video images can be delayed, which can result in incomplete or inaccurate real-time decision-making.

3.2.5 STORAGE

Description: Video can be used for real-time (e.g., monitoring or tactical) applications or stored for future analysis. Improperly stored video may be unusable due to loss or degradation of data; for example, improper storage of video would be a critical issue in evidentiary and forensic video applications. Video must be stored simultaneously at a high bitrate and low bitrate to prevent irretrievable data loss. For example, some systems may provide a low bitrate stream for wireless monitoring while simultaneously storing a higher bitrate version locally.

In order to decrease the bitrate, storage is also often preceded by some form of processing. File format can be altered to fit different media, such as coding the video in MPEG 2 for storage on a DVD and playback with a DVD player. A series of alterations or physical custody changes made to a video file is called the "storage chain." The storage chain should be monitored and documented very closely since almost every change in file format results in a loss of data.

Attributes that might affect video quality

- Physical degradation of storage media over time (e.g., tapes stretching, breaking or being exposed to magnetic fields).
- Physical custody of the media.

3.2.6 DISPLAY

Description: To present a true quality picture of video footage captured, the emergency response community depends on a good quality image display unit to aid in accurately communicating information to the end users.

Public safety agencies are increasingly using display functions—EMS for medical diagnosis, fire for research and training, and law enforcement for evidence in the courtroom. Selecting the proper display for the end user's specific video applications can be as important to achieving the user's goal for the video footage as selecting the appropriate camera equipment.

Attributes that might affect video quality

- "Trueness" of the colors displayed.
- Aspect ratio used.

3.3 RECOMMENDATION TOOL FOR VIDEO REQUIREMENTS RESULTS

The PSCR developed an online tool entitled the *Recommendation Tool for Video Requirements* [5], which is based on the GUC framework and the *Defining Video Quality Requirements: A Guide for Public Safety* [4] document. The input to this tool consists of the five GUC aspects. The output from the tool provides a set of recommendations and references to help the public safety community understand the impact of the video system components on video quality. One notable output of this tool is the recommended encoding bitrate, which is generally correlated with the quality of the video.

JHU/APL used the PSCR online recommendation tool [5] to develop the video bitrate requirements shown in Figure 4. A total of 96 possible recommendations could be derived from the five GUC aspects using the tool. However, the quality requirements for live (real-time) use and recorded use were identical. Taking this into consideration, JHU/APL did not consider the "recorded" characteristic when choosing the criteria for the GUC aspects. Consequently, 48 specific recommendations were obtained directly from the online tool. The results were then tabulated to show the connection between the four remaining GUC aspects, contributing criteria and the recommended encoding bitrates (Figure 4).

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

Figure 4 Recommended Encoding Bitrate

Referring to Figure 4, when we examine the GUC aspects consisting of variable lighting, small target size and high motion, the recommended encoding bitrates for "Target Positive ID" and "General Elements of the Action" are 2048 kbps and 512 kbps, respectively (see the yellow highlighted rows in Figure 4). Correspondingly, when we examine the suggested encoding bitrates for "Low Motion," the resulting bitrates are 2048 kbps and 256 kbps.

We can also observe that the recommended encoding bitrate shown in the last two columns of Figure 4 correlates with the Discrimination Level. For example, "Target Positive ID" requires 2048 kbps, while "General Elements of the Action" requires either 512 kbps (high motion) or 256 kbps (low motion). Assuming other conditions are similar, a use case requiring "Target

Positive ID" will generally require higher bitrates compared to a use case requiring only "general elements of action."

As previously mentioned, the tool provides other useful recommendations and references to help the public safety stakeholder understand and minimize the impairment to video quality from video system components. For example, in situations where the GUC accommodates dim lighting, the tool recommends a camera with the ability to capture images with low lux, slow shutter speed, and infrared and black and white (B&W) capabilities. This is supplemented with additional guidelines on resolution, bandwidth, storage requirements and other suggestions.

More information on the video quality requirements recommendation tool and other resources can be found on the PSCR VQiPS website [7].

3.3.1 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 PSCR *Assessing Video Quality for Public Safety Applications Using Visual Acuity, Public Safety Communications Technical Report* [11] published in November 2012, are the *minimum* recommended by PSCR. There may be 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. As a result, that study recommended the maximum encoded bitrate [11]. Additionally, advances in encoder technologies and hardware capabilities since this 2012 study will likely have an impact on the choice of encoder parameters and assessment results.

The PSCR used the following resolutions and encoder settings (Figure 5) 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 the 640 x 480 format for encoding. The files were compressed using H.264 [12] with the settings shown in Figure 5.

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 5 Encoder Setting for Visual Acuity Used by the PSCR

4 VIDEO FILE DESCRIPTION AND BITRATE

From a high-level perspective, a typical digital video file consists of individual images sequenced over a period of time, which may also include audio information and overhead data. Each video frame (essentially an individual image captured by the image sensor through the lens) is combined with subsequent image frames over a period of time to create a video file. The rate at which bits are processed or transferred is the bitrate. Bitrate is a function of three attributes: video frame size, frame rate and the compression standards (Figure 6).

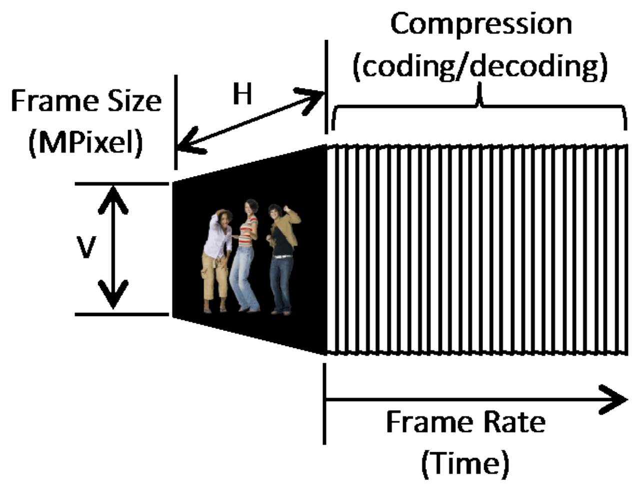

Figure 6 Video File Attributes

4.1 VIDEO FILE ATTRIBUTES

Frame size (MPixel)

The video frame size is the product of the horizontal (H) and vertical (V) resolution in pixels or Megapixels (MPixel). For example, a resolution of 640 X 480 will result in 307,200 pixels or 0.3 MPixels, while a 1920 X 1080 resolution will result 2,073,600 pixels or 2.1 MPixels.

Frame rate (Time)

Frame rate is the number of individual video frames captured/displayed over a duration of time. It is typically expressed as frames per second (fps). Frame rate determines how smooth the motion is captured and displayed. For example, a frame rate of 30 fps means 30 individual images appear sequenced over a period of one second. The number of images over this period determines how smooth the motion appears. The three primary frame rate standards are 24, 25 and 30 fps [25].

Compression

Uncompressed video data consumes an enormous amount of resources. As a result, digital video files are typically compressed to reduce storage and transport requirements. There are many different video coder-decoder (codec) standards, such as the H.264/MPEG-4 AVC [12] and the MPEG-4 Part 2 [13], used to reduce the resource requirements for video over resource limited networks.

Container

Although it is not illustrated in Figure 6, a video "container" is an integral part of the video package. Containers are used to package, transport and display audio-video data. It is the combination of the video, audio and other data wrapped in a format needed by the destination hardware to decode and display the media content. Some examples of well-known container formats include: Moving Pictures Experts Group Layer 4 (.mp4), Apple QuickTime (.mov/.qt), Adobe Flash (.flv) and Microsoft Audio Video Interleave (.avi).

4.2 VIDEO BITRATE

Bitrate is the rate at which bits are processed or transferred. It is typically expressed as bits per second (bps), kilobits per second (kbps) or megabits per second (Mbps). It can also be expressed as kilobytes per second (kBps) or megabytes per second (MBps). We can use a basic formula to understand the impact of frame size (resolution) on video bitrates [14][15]:

$$\textit{RAW Video Bitrate} = \textit{Resolution} \times \textit{Color Depth} \times \textit{Frame Rate} \qquad \textit{(Equation 1)}$$

For simplicity, certain assumptions are made: (1) RAW bitrate is calculated with encoding not used; (2) the color depth is assumed to be 8-bit[1]; and (3) the frame rate is assumed to be 30 frames per second (fps). The RAW bitrate can be calculated based on these assumptions and using a frame size of 640 × 480 pixels. After applying these assumptions and frame size to the above formula (Equation 1), the RAW video bitrate is calculated to be 73,729 kbps or 73.7 Mbps.

$$\textit{RAW Video Bitrate} = (640 \times 480) \times 8 \times 30$$
$$\textit{RAW Video Bitrate} = 73{,}729 \textit{ kbps or } 73.7 \textit{ Mbps}$$

If we use the same formula (Eq. 1) with a higher resolution (1920 × 1080), we can estimate the RAW video bitrate to be 497,664 kbps or 497.6 Mbps.

$$\textit{RAW Video Bitrate} = (1920 \times 1080) \times 8 \times 30$$
$$\textit{RAW Video Bitrate} = 497{,}664 \textit{ kbps or } 497.6 \textit{ Mbps}$$

From these calculated results, we can observe that the bitrate increased by a factor of 7 when the resolution was increased from 640 × 480 (73.7 Mbps) to 1920 × 1080 (497.6 Mbps). Figure

[1] 8-bit color depth is a limited true color system with 2^8 or 256 colors. There are various color depths, including 1-bit (2^1 or two colors, black and white), 24-bit (2^{24} or 16,777,216 colors), etc.

7 shows the resulting bitrates after additional resolutions were applied to Equation 1. As this chart shows, the bitrate increases significantly as the resolution increases.

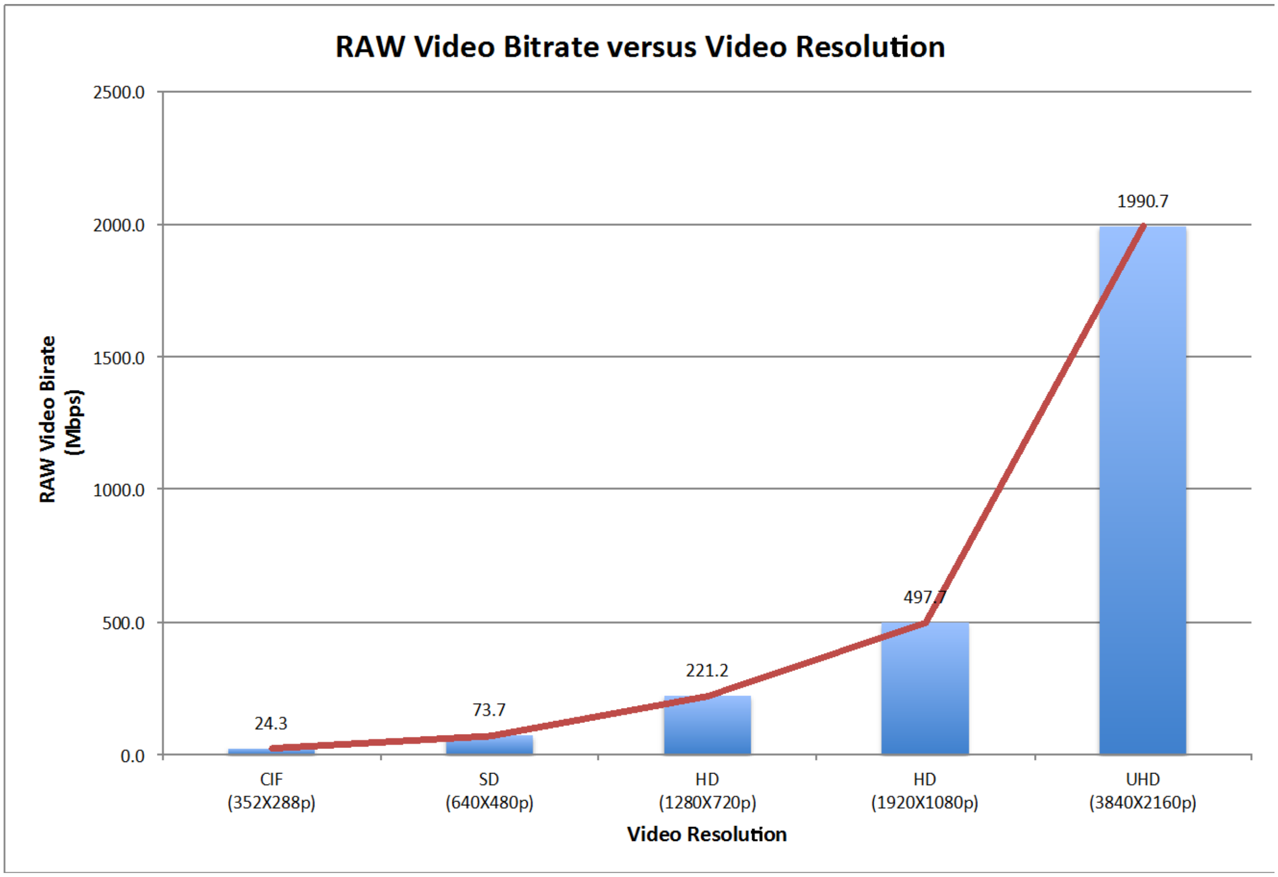

Figure 7 RAW Video Bitrate vs. Video Resolution

The frame rate can also be shown to have an effect on the video bitrate. If we change the frame rate from 30 fps to 60 fps, while keeping the resolution and color depth constant at 1920 X 1080 and 8-bits respectively, the RAW bitrate doubles (from 497.6 Mbps to 995.3 Mbps).

$$RAW\ Video\ Bitrate = (1920 \times 1080)\ \times 8 \times 30$$
$$RAW\ Video\ Bitrate = 497{,}664\ kbps\ or\ 497.6\ Mbps$$

$$RAW\ Video\ Bitrate = (1920 \times 1080)\ \times 8 \times 60$$
$$RAW\ Video\ Bitrate = 995{,}328\ kbps\ or\ 995.3\ Mbps$$

Likewise, if we change the frame rate from 30 fps to 15 fps, we can observe that the bitrate decreases by half (from 497.6 Mbps to 248.8 Mbps).

$$RAW\ Video\ Bitrate = (1920 \times 1080) \times 8 \times 15$$
$$RAW\ Video\ Bitrate = 248{,}832\ kbps\ or\ 248.8\ Mbps$$

Additional frame rates were calculated, and the resulting bitrates are charted in Figure 8. As the chart shows, the bitrate increases as the resolution increases.

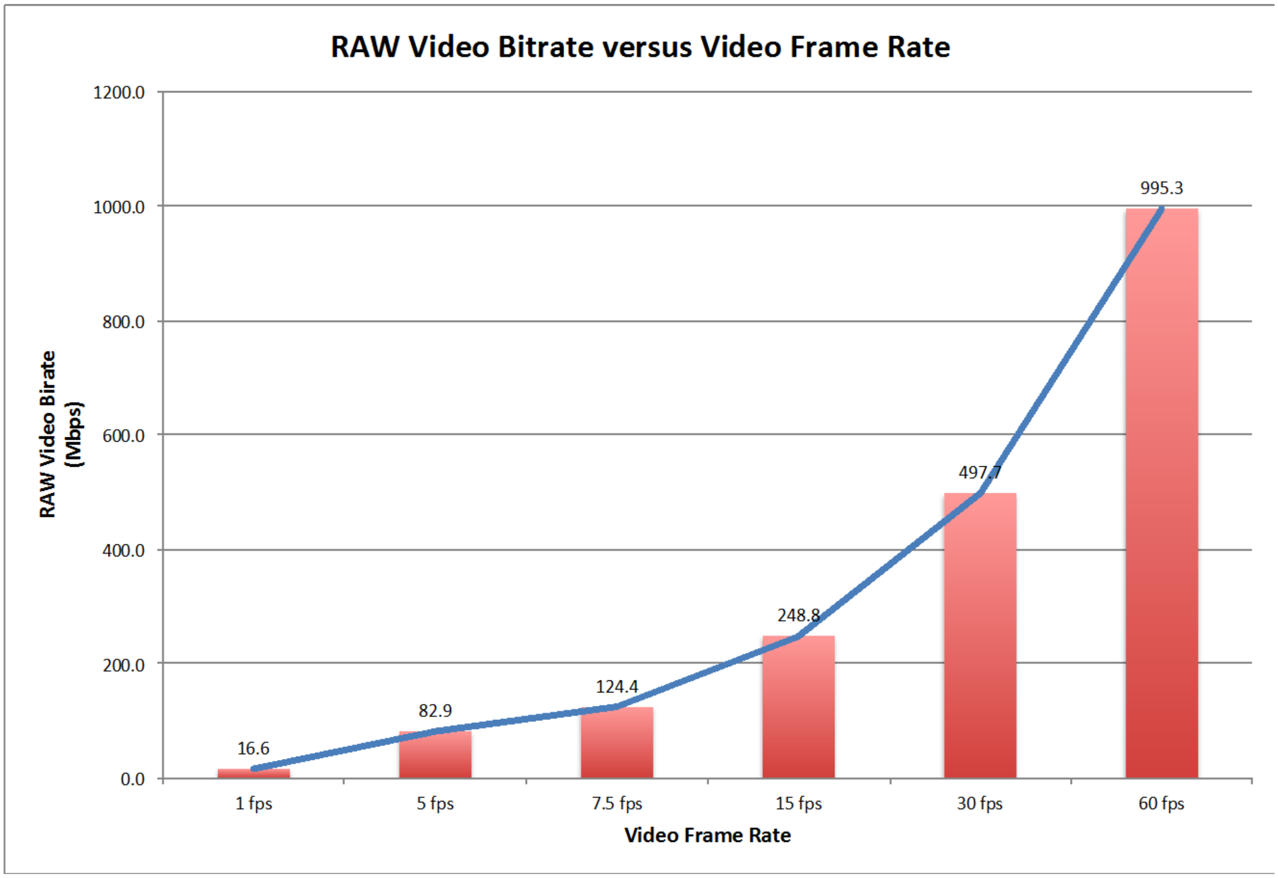

Figure 8 RAW Video Bitrate vs. Video Frame Rate

The calculations above demonstrate how bitrates correlate to the video file attributes. A video file may also contain audio information and metadata, but these have relatively insignificant effects compared to the video portion. Therefore, the calculations were focused only on the video component.

From a network bandwidth and storage standpoint, video bitrate is an important parameter because it has direct impact on network bandwidth and video quality. If the available bandwidth cannot meet the minimum video bitrate requirement, then packet delay or loss can occur, which will impact the delivered video quality to the end user(s).

4.3 CODER/DECODER

After the initial video acquisition and capture process, compression is one of the most important factors that can affect video quality. Uncompressed video has a considerable impact on the resources required to transmit and store the data, so video is typically compressed. Compression serves to reduce the video data size to a more manageable level for transport and storage, while attempting to maintain a certain level of acceptable quality. Too much compression will result in poor video quality, while too little compression will result in a video file that is larger than necessary.

Compression can be lossless[2] or lossy[3], and encoded at a constant bitrate (CBR) or variable bitrate (VBR). VBR encoding will generally provide higher quality for a smaller final file size, but it typically takes longer to encode than CBR. Video coding techniques can use intraframe compression or interframe compression. Intraframe compression is less computationally intensive than interframe compression because each video frame contains all the necessary information. In contrast, interframe compression groups adjacent video frames together that then reference each other and use temporal redundancy to obtain increased compression. While interframe compression produces smaller video files of similar quality compared to intraframe compression, it requires more processing power because the entire frame group has to be examined instead of a single frame.

Many encoding standards exist. The simplest use only intraframe compression. For example, Motion JPEG (M-JPEG) is an intraframe compression scheme developed from the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 10918-1:1994 standard [16] and released by the Joint Photographic Experts Group (JPEG). M-JPEG consists of image frames independently compressed and sequenced over time to form motion video. Intraframe encoding is not very efficient, but has advantages in simplicity and therefore faster processing. The Telecommunication Standardization Sector of the International Telecommunication Union's (ITU-T) Video Coding Experts Group (VCEG) and ISO/IEC Joint Technical Committee's (JTC1) Motion Picture Expert Group (MPEG) jointly developed the H.264 or MPEG-4 (Part 10) Advanced Video Coding (AVC) standard known as ITU-T H.264 [12]. H.264/AVC is an example of an interframe compression standard. These encoding standards can operate at different bitrates and quality levels. Modern encoding schemes attempt

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[2] In lossless compression, the original data can be restored after decompression without any loss of the data. The compression efficiency is relatively low compared to lossy compression.

[3] In lossy compression, the original data is lost and cannot be recovered after decompression. The compression efficiency can be much higher compared to lossless compression.

to adapt to network conditions by adjusting the bitrate and quality based on feedback from the decoder. The behavior of the codec can be very complicated, and choices made regarding the codec will be important to the NPSBN.

An examination of the codecs available on Internet Protocol (IP) network based surveillance cameras reveal that M-JPEG and H.264 are the two options available on many commercially available camera systems. For example, both AXIS communications and CISCO offer network connected IP cameras with H.264 and M-JPEG encoding capabilities [17][18]. These two codec standards appear widely adopted for modern surveillance camera systems.

A new generation of codecs is being developed to offer both more efficiency and better video quality. The ISO/ICE JTC1 Motion Picture Experts Group and ITU-T Video Coding Experts Group are jointly developing the promising new codec the High Efficiency Video Coding (HEVC) or the MPEG-H Part 2/ITU-T H.265 [19], which was ratified as a standard on April 13, 2014. The goal of HEVC is to develop an encoding standard to support up to 8K Ultra High Definition (UHD) by providing twice the compression efficiency of H.264. H.265 does this by compressing the images into different block sizes based upon complexity (what changes from frame to frame versus what does not change). Using larger block sizes when possible allows lower complexity parts of the image to be described more efficiently. Also, H.265 can encode motion vectors at a higher precision than H.264 (i.e., H.265 allows 35 intra-picture directions, while H.264 allows only 9). The improvements offered by H.265 can reduce network resource requirements for transmission and storage, while maintaining similar video quality as compared to H.264/AVC encoded video. The NPSBN can benefit from this new codec standard by allowing more efficient use of limited network resources, while maintaining video quality requirements.

Ohm et al. published a paper entitled *Comparison of the Coding Efficiency of Video Coding Standards – Including High Efficiency Video Coding (HEVC)* [20], which studied the coding efficiency of the HEVC codec standard and compared various other predecessor codecs. Figure 9 shows the efficiency in terms of average bitrate savings of HEVC codec compared against the H.264/AVC codec.

Sequences	Bit-Rate Savings of HEVC MP Relative to H.264/MPEG-4 AVC HP
BQ Terrace	63.1%
Basketball Drive	66.6%
Kimono 1	55.2%
Park Scene	49.7%
Cactus	50.2%
BQ Mall	41.6%
Basketball Drill	44.9%
Party Scene	29.8%
Race Horses	42.7%
Average	49.3%

AVERAGE BIT-RATE SAVINGS FOR ENTERTAINMENT APPLICATION SCENARIO BASED ON SUBJECTIVE ASSESSMENT RESULTS

Source: http://ieexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=631756

Figure 9 HEVC Bitrate Savings Compared to AVC

An average saving of 49.3p can be observed from the bitrate savings table in Figure 9 above. Extrapolating this savings into Mission Critical Video (MCVideo) applications, the bandwidth requirements on the NPSBN can be reduced by approximately half for a given video, while still maintaining a comparable level of video quality. Because the bitrate is an important parameter affecting video quality and bandwidth requirements on the transport network, improvements in compression efficiency should be very advantageous.

The expected efficiencies from the H.265/HEVC codec promise substantial improvements for supporting video over a limited bandwidth network. While this is advantageous for video performance, questions related to the licensing of the technology remain unresolved. The H.265/HEVC standard is based on intellectual properties owned by many different entities. Although the H.264/AVC technology (predecessor to H.265/HEVC) faced similar challenges, the intellectual property owners were represented by a single organization that administered the licensing of their technology. In contrast, H.265/HEVC patent holders have formed two separate licensing groups and, even when combined, these two groups do not represent all the relevant parties [21]. The cost associated with licensing this codec is also estimated to be significantly higher than H.264 and with no known upper boundary limits. Additionally, the use of H.265 in freely distributed software, such as an Internet browser, is restricted. The uncertainty of licensing fees, ownership and other issues surrounding the use of this technology creates a layer of complexity potentially limiting its use. Despite H.265/HEVC technology having tremendous

momentum, wide scale adoption by the industry may be hampered without an effective solution to these issues.

An alternative to the H.265/HEVC codec is Google's VPx coding technology. Unlike H.265/HEVC or H.254/AVC, the VPx coding technology is open source and royalty-free. VP9 is the current generation of coding format that is available. It is similar to H.265/HEVC in that it nearly halves the capacity required when compared to H.264/AVC of similar video quality [22]. VP9 uses somewhat similar compression techniques (e.g., different sized blocks) to those described above for H.265, but with the advantage of being open source. As a result, VPx does not have the intellectual property issues surrounding H.265/HEVC mentioned above. Google is currently developing the next iteration of VPx codec to VP10. Google expects to further shrink the bandwidth requirement to half that of VP9, while enhancing image quality by providing faster frame rates, improving dynamic range and increasing color range [23]. Even though the legal and financial benefits may be clear, the technology has not been widely embraced by industry. The CEO of Encoding.com, Greggory Heil, stated, "Most of our research concludes that VP9 is far less mature than HEVC and offers inferior compression rates" [24]. Still, with the financial and legal issues encumbering H.265/HEVC codec introduction, Google's open source and royalty free technology may play a bigger role in the future.

4.4 VIDEO FILE SUMMARY

Video bitrate is an important parameter indicating video quality and network bandwidth requirements. It is the rate at which bits are processed and transferred. It consists of three attributes: frame size, frame rate and compression scheme, as shown in Figure 6. It is typically expressed as bits per second (bps), kilobits per second (kbps) or megabits per second (Mbps).

New advances in video codec standards, such as H.265/HEVC or VP10, promise meaningful reductions in video file size, while maintaining video quality. Similarly, the same codec can be used to increase video quality, while maintaining video data size. These benefits should be studied and leveraged to decrease the load on the NPSBN.

5 VIDEO QUALITY INDICATOR ACROSS THE NPSBN

The VQiPS WG is interested in determining the required high, medium or low quality levels for public safety video data over the NPBSN. These three generic terms were used in the NPSTC *Public Safety Communications Assessment* Report [1], but have not been sufficiently quantified. As discussed above, the VQiPS WG and the PSCR program have done extensive work to develop video quality parameters based upon use cases and generalized use classes. Leveraging this work, the GUC concept can provide the information needed to define the mission requirements video quality level.

Video quality is characterized by the ability to use the video to perform the intended purpose, whether for general crowd monitoring or more detailed identification. If the mission requires "Target Positive ID," high quality video should be required to have sufficient detail to make positive recognition. Figure 10 reminds us how the discrimination level correlates to the intended purpose of the video in the PSCR GUC framework.

DISCRIMINATION LEVEL	DESCRIPTION
Target Positive ID	Enough detail to make positive recognition, such as a face, an object, or alpha-numeric characters
Target Class Characteristics	Medium-scale detail recognition, such as gender, markings, smaller actions
Target Class Recognition	Large-scale recognition, such as a car versus a van
General Elements of the Action	High-level description of actions that took place, such as of people, a person, or a vehicle

Figure 10 Discrimination Level Description

In order to map the three generic terms of high, medium and low quality to the discrimination level, a video quality indicator (VQI) is introduced. VQI is used to associate the discrimination level, shown in Figure 10, to the level of detail described in the GUC (Figure 11). Video used for "Target Positive ID" would require HIGH quality with enough detail to make positive identification of a specific person or item. Video used for "Target Class Characteristics" or "Target Class Recognition" would require MEDIUM quality sufficient for recognition of intermediate scale details, such as the ability to distinguish a car versus a van, or recognize the gender of a person. Finally, video used for "General Elements of the Action" would only require LOW quality for more general and less detailed observations.

VIDEO QUALITY INDICATOR (VQI)	DISCRIMINATION LEVEL	DESCRIPTION
HIGH	Target Positive ID	Enough detail to make positive recognition, such as a face, an object, or alpha-numeric characters
MEDIUM	Target Class Characteristics	Medium-scale detail recognition, such as gender, markings, smaller actions
MEDIUM	Target Class Recognition	Large-scale recognition, such as a car versus a van
LOW	General Elements of the Action	High-level description of actions that took place, such as of people, a person, or a vehicle

Figure 11 Video Quality Indicator Mapping

As previously explained, the Discrimination Level that must be met by the video in order to meet the mission requirement is an important characteristic of the GUC. Likewise, video bitrate is an important characteristic when determining the overall video quality and its impact on network bandwidth and storage requirements.

Using the video requirements tool with the four GUC aspects, mentioned in Section 3.3, resulted in 48 individual encoding bitrates (Figure 4). This data was then sorted by discrimination level, linked to the VQI, and tabulated with the remaining GUC aspects (i.e., target size, motion and light) in order to reveal other conditions contributing to the recommended encoding bitrate. The tables for LOW VQI (Figure 12), MEDIUM VQI (Figure 13) and HIGH VQI (Figure 14) were then used to determine the range of recommended bitrates for each VQI. As can be seen from these tables, the video requirements tool recommends a bitrate range of 64 kbps to 512 kbps for low quality, 64 kbps to 2048 kbps for medium quality, and 128 kbps to 2048 kbps for high quality.

LOW VQI											
DISCRIMINATION				TARGET		MOTION		LIGHT			RECOMMENDED ENCODING BITRATE (kbps)
GENERAL ELEMENTS OF THE ACTION	TARGET CLASS RECOGNITION	TARGET CLASS CHARACTERISTICS	TARGET POSITIVE ID	LARGE	SMALL	HIGH	MINIMAL	CONSTANT LIGHTING BRIGHT	CONSTANT LIGHTING DIM	VARIABLE LIGHTING	
✓				✓		✓		✓			64
✓				✓			✓	✓			64
✓				✓		✓			✓		128
✓				✓			✓		✓		128
✓					✓	✓		✓			128
✓					✓		✓	✓			128
✓				✓		✓				✓	256
✓				✓			✓			✓	256
✓					✓		✓		✓		256
✓					✓		✓			✓	256
✓					✓	✓			✓		512
✓					✓	✓				✓	512

Figure 12 Range of Bitrates for Low VQI

MEDIUM VQI											
DISCRIMINATION				TARGET		MOTION		LIGHT			RECOMMENDED ENCODING BITRATE (kbps)
GENERAL ELEMENTS OF THE ACTION	TARGET CLASS RECOGNITION	TARGET CLASS CHARACTERISTICS	TARGET POSITIVE ID	LARGE	SMALL	HIGH	MINIMAL	CONSTANT LIGHTING BRIGHT	CONSTANT LIGHTING DIM	VARIABLE LIGHTING	
		✓		✓			✓	✓			64
		✓		✓		✓		✓			128
		✓			✓	✓		✓			128
		✓			✓		✓	✓			128
		✓		✓			✓		✓		256
		✓		✓		✓			✓		512
		✓		✓			✓			✓	512
		✓			✓		✓		✓		512
		✓		✓		✓				✓	1024
		✓			✓	✓			✓		1024
		✓			✓		✓			✓	1024
		✓			✓	✓				✓	2048
	✓			✓		✓		✓			64
	✓			✓			✓	✓			64
	✓			✓			✓		✓		128
	✓				✓	✓		✓			128
	✓				✓		✓	✓			128
	✓			✓		✓			✓		256
	✓				✓		✓		✓		256
	✓			✓			✓			✓	512
	✓				✓	✓			✓		512
	✓				✓	✓				✓	512
	✓			✓		✓				✓	1024
	✓				✓		✓			✓	1024

Figure 13 Range of Bitrates for Medium VQI

HIGH VQI											
DISCRIMINATION				TARGET		MOTION		LIGHT			RECOMMENDED ENCODING BITRATE (kbps)
GENERAL ELEMENTS OF THE ACTION	TARGET CLASS RECOGNITION	TARGET CLASS CHARACTERISTICS	TARGET POSITIVE ID	LARGE	SMALL	HIGH	MINIMAL	CONSTANT LIGHTING BRIGHT	CONSTANT LIGHTING DIM	VARIABLE LIGHTING	
			✓	✓			✓	✓			128
			✓		✓		✓	✓			128
			✓		✓	✓		✓			256
			✓	✓			✓		✓		512
			✓		✓		✓		✓		512
			✓	✓		✓		✓			1024
			✓	✓		✓			✓		1024
			✓	✓		✓				✓	1024
			✓	✓			✓			✓	1024
			✓		✓	✓			✓		2048
			✓		✓	✓				✓	2048
			✓		✓		✓			✓	2048

Figure 14 Range of Bitrates for High VQI

The preceding tables show that the bitrate range is the lowest for the LOW VQI and highest for the HIGH VQI. This is in agreement with the notion that higher bitrates give higher quality results. Challenging conditions, such as variable lighting or high motion, can also contribute to higher bitrates. For example, HIGH VQI with small target size, minimal motion and constant bright light results in a recommended bitrate of 128 kbps, while a variable lighting condition results in a recommended bitrate of 2048 kbps. As illustrated in Figure 15, the bitrates generally

increase as the level of detail increases and/or the conditions of the GUC aspects become more challenging.

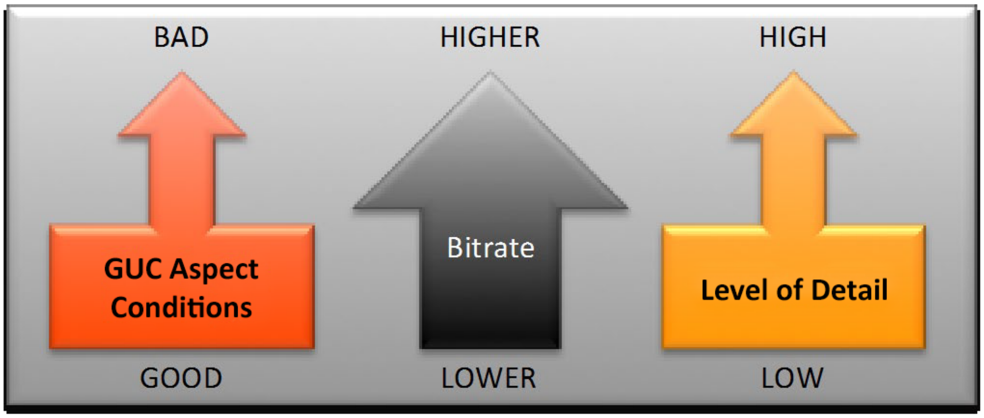

Figure 15 Bitrate versus Characteristics

6 VQIPS GENERALIZED USE CLASS APPLICABILITY TO NPSTC USE CASES

JHU/APL took the original use cases developed by the NPSTC found in the *Use Cases & Requirements for Public Safety Multimedia Emergency Services* report [8] and used them to derive a subset that uses video [26]. JHU/APL prepared the use cases at a high-level and to be representative models in order to provide input into the 3GPP Standards development process. Although these use cases did not contain all the necessary details, they were used to demonstrate the functional capabilities of the GUC framework outlined in Section 3.

Details of some GUC aspects could be easily identified from the use cases, but assumptions had to be made for some others to map them into the GUC concept. For example, NPSTC Use Case 9 - Variant 1 (see yellow highlighted row in Figure 16) is a pursuit scenario in which video is used for an Automatic License Plate Reader (ALPR) application. The level of detail needed for the intended purpose of the video is mentioned (automatic license reader), but no other details are specifically referenced. Because this use case involves a vehicle pursuit, the environment was assumed to be outdoors in bright and sunny conditions, with high motion and small target size. Of course, other assumptions could be made, but the missing details were developed around the context of the use case for demonstrative purposes.

USE CASES						
NPSTC USE CASE	VARIANT	DETAIL DESIRED	USAGE TIMEFRAME	TARGET SIZE	MOTION	ENVIROMENT
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 16 NPSTC Use Case Attributes

Once some reasonable assumptions were made to complete the missing details, the use cases and variants were mapped to the appropriate use class characteristics and into the *Recommendations Tool for Video Requirements* [5] to obtain the recommended encoding bitrate. The results were tabulated as shown in Figure 17. This table shows the correlation between the VQI, Discrimination Level and encoding bitrate.

USE CLASS								VIDEO QUALITY INDICATOR (VQI)
NPSTC USE CASE	VARIANT	DISCRIMINATION LEVEL	USAGE TIMEFRAME	TARGET SIZE	MOTION	LIGHT LEVEL	ENCODING BITRATE (kbps)	
4	1	Target Positive ID	Live or real-time	Small	Minimal	Constant Lighting - Dim	512	High
4	2	Target Positive ID	Live or real-time	Small	Minimal	Constant Lighting - Dim	512	High
4	3	General Elements of the Action	Live or real-time	Small	Minimal	Constant Lighting - Dim	256	Low
4	5	General Elements of the Action	Live or real-time	Small	Minimal	Constant Lighting - Dim	256	Low
4	6	General Elements of the Action	Live or real-time	Small	Minimal	Constant Lighting - Dim	256	Low
9	1	Target Positive ID	Live or real-time	Small	High	Constant Lighting - Bright	256	High
9	2	Target Positive ID	Live or real-time	Small	High	Constant Lighting - Bright	256	High
9	3	General Elements of the Action	Live or real-time	Small	High	Constant Lighting - Bright	128	Low
9	4	General Elements of the Action	Live or real-time	Small	High	Constant Lighting - Bright	128	Low
9	6	General Elements of the Action	Live or real-time	Small	High	Constant Lighting - Bright	128	Low
9	7	General Elements of the Action	Live or real-time	Small	High	Constant Lighting - Bright	128	Low
11	1	General Elements of the Action	Live or real-time	Small	Minimal	Constant Lighting - Bright	128	Low
14	1	General Elements of the Action	Live or real-time	Small	Minimal	Constant Lighting - Dim	256	Low
14	7	Target Positive ID	Live or real-time	Large	Minimal	Variable Lighting	1024	High

Figure 17 GUC Use Class Output with VQI

If we closely examine the use case highlighted in yellow (Figure 17), we can see that the desired Discrimination Level is associated with "Target Positive ID," consisting of the following characteristics: real-time, small target size, high motion and bright environment. This particular use case requires "enough detail to make positive recognition" (Figure 10) due to the fact that ALPR is mentioned. In combination with the other characteristics of the use class aspects, this requirement results in a HIGH VQI with a *minimum* recommended encoding bitrate of 256 kbps. This implies that bitrates below 256 kbps will likely result in insufficient video quality to meet the mission requirements. Alternatively, bitrates above 256 kbps will likely result in suitable video quality, but the file size may be unnecessarily large.

Assumptions had to be made in the example above to show the application of the use cases to the VQiPS GUC framework. In order to better utilize the *Recommendations Tool for Video Requirements*, and the references and guidelines provided through the VQiPS process, all the GUC aspects should be considered when use cases are developed.

7 VIDEO DESIGN IMPROVEMENT

As noted in Section 3, video quality is described as the ability of the public safety end user to use the required video to perform the purpose intended. Each component in the video system can negatively impact the quality of the video delivered to the end user. In an ideal world with no limitations of resources, every part of the video system could work in tandem to deliver the highest possible quality. Unfortunately, limitations do exist and may have an adverse impact on video quality.

Networks based on the 3GPP LTE standards hold the promise of increased capacity, speed and reduced cost over earlier generation wireless networks. Despite these benefits, LTE is still fundamentally constrained in the amount of available resources because of spectrum limitations. Congestion can occur when the demand for resources exceed the available capacity. This will be of significant concern to the first responder community due to the mission critical nature of public safety. A systematic "end to end" view of the video requirements, video system and the network has to be considered in order to improve the video design process and address the challenges of delivering video over LTE.

7.1 SYSTEMATIC VIDEO DESIGN APPROACH

In order to improve the video design process, the entire video system has to be considered. The video quality requirements and the demand for competing resources must be balanced with limited network capacity. The tools found within the LTE network alone will be insufficient. A framework consisting of MISSION, CONTENT and TRANSPORT NETWORK (MCTn) is proposed in Figure 18 to deliver this resource intensive service on the NPSBN.

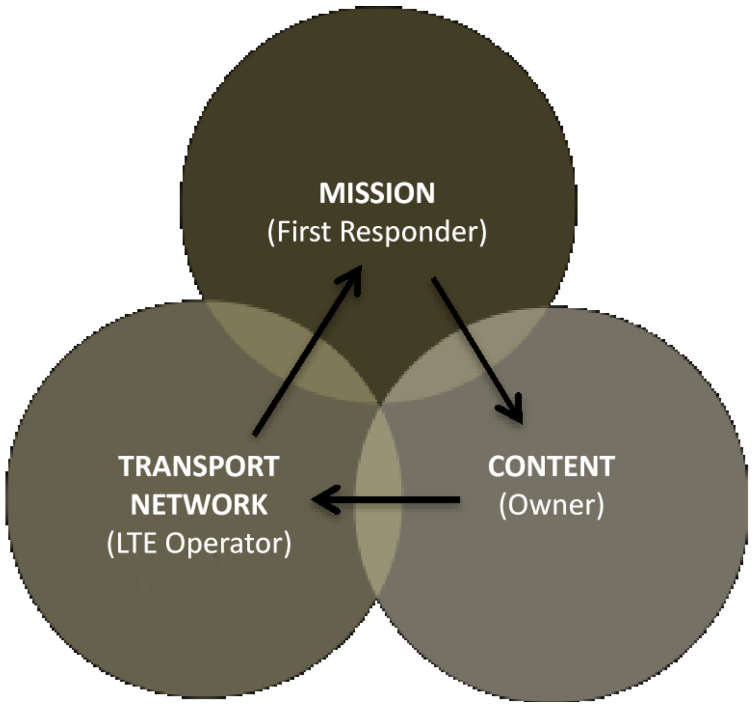

Figure 18 MCTn (Mission, Content and Transport Network) Framework

The MISSION *defines the video quality requirement and priority of the user* to successfully complete the operational objective. During times of emergencies or network congestion, the end-user ideally receives the video with "just enough" data to meet their requirements 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 weather conditions? Providing the appropriate level of video quality will meet the mission need and maximize the use of available network resources.

CONTENT *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?

The TRANSPORT NETWORK *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?

The MCTn framework attempts to efficiently utilize the LTE network by balancing the end user's video requirement with the smallest file size possible and with the proper consideration of the user priority to meet the needs of the MISSION. The video design process should incorporate the requirements of video quality as specified by the mission to ensure that the content owner provides "just enough quality" to meet the needs of the end user and the capabilities of the display device.

A more detailed explanation and development of the MCTn Framework can be found in the *Advance Communications Video over LTE: Efficient Network Utilization Research* paper drafted by JHU/APL [27].

7.2 VIDEO DESIGN IMPROVEMENT REFERENCE MODEL

The Video Design Improvement Process Reference Model (Figure 19) is introduced to show the relationship between the MCTn framework and the various parts of the VQiPS video requirement recommendation process. High-level blocks serve as functional descriptions to help align the MCTn framework to the VQiPS concepts.

As shown below, the MISSION component consists of the user and use case blocks. These functional blocks define the video quality requirement to the content owner, as well as establish the priority. From a VQiPS perspective, they are equivalent to use cases. The blocks pose the questions: Who needs the video? What does he/she need (Discrimination level)? When does he/she need it (Content Analysis)? How (Observation)?

The CONTENT component consists of the PARAMETER, VIDEO SYSTEM COMPONENT and OUTPUT blocks, which are also shown in blue in Figure 19. These functional blocks convey the quality requirements in order to ensure that the output of the video system meets the mission requirements. From a VQiPS perspective, they are equivalent to applying the GUC concept and using the tools and resources to derive the quality requirements for the video system. This step should include the understanding of what is needed, and how the video will be used and displayed in order to serve up the necessary files having the smallest impact to the network bandwidth in high, medium and low qualities.

The TRANSPORT Network component consists of the TOOLS block. This functional block uses the tools available on the LTE network to control and augment resources to deliver the video data at the required quality during times of congestion.

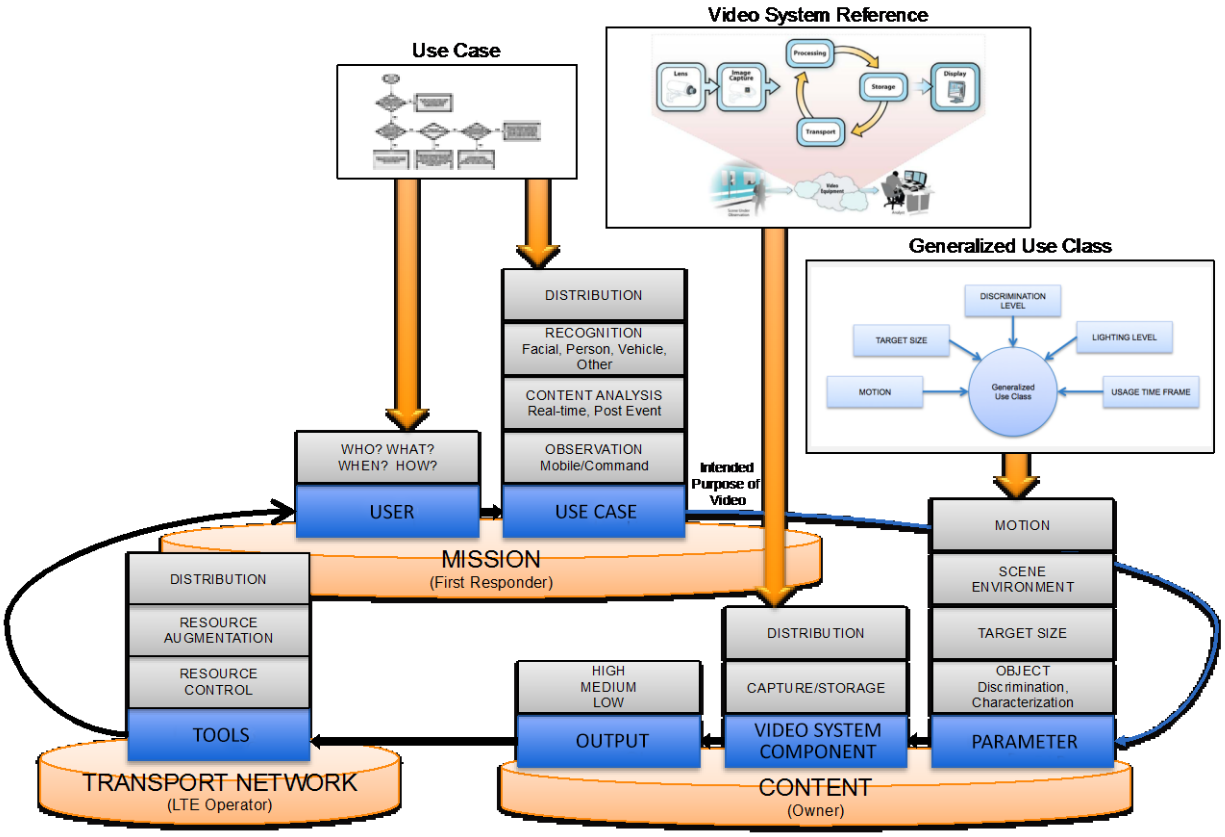

Figure 19 Video Design Improvement Process Reference Model

As can be seen from the Video Design Improvement Process Reference Model, the MCTn framework aligns with the existing VQiPS video requirements process. The VQiPS process has established a solid foundation on which the delivery of video can be viewed holistically. The extensive tools and resources available on the PSCR VQiPS website can be leveraged and extended to improve the video design process by linking it to the proposed MCTn framework and observations from the NPSTC use cases.

8 SUMMARY

This paper documents the efforts of the VQiPS WG and PSCR programs with regards to the GUC and video system reference concepts, and expands upon the current video quality requirements guide to identify values for key parameters (target size, motion, lighting level, usage, discrimination level, frame rate, etc.) that would equate to high, medium and low quality as transmitted over the NPSBN. It leverages use cases derived from NPSTC to identify potential

opportunities to improve the video design process with respect to video transmission over a wireless network. It also proposes a framework to consider video design from a holistic standpoint in order to facilitate the delivery of video data without compromising public safety or degrading wireless bandwidth unnecessarily.

The extensive work done by the VQiPS PSCR program aptly sets the stage to quantify the parameters having an impact on video quality and network resource requirements. Tools and resources are available to help guide the design of a video system (Section 3). Video practitioners in public safety can use these tools and resources as the basis to develop component level requirements. While many specific requirements can be derived from the VQiPS PSCR tools and resources, one notable requirement (encoding bitrate) can be determined from the *Recommendation Tool for Video Requirements* (Section 3.3). Bitrate is important for both the NPSBN and VQiPS because it characterizes network resource requirements and video quality.

The VQiPS WG describes video quality as the ability of the public safety end user to utilize the required video to perform the purpose intended. Using this definition, the encoding bitrate and the discrimination level can be correlated to a VQI (high, medium or low quality) and the corresponding bitrate ranges derived for use over the wireless network (Section 5).

Development of use cases to identify video quality requirements is an essential part of the video design process. The NPSTC use cases were used to demonstrate the benefits of the VQiPS PCSR video quality requirement process in determining the encoding bitrate (Section 6). The range of bitrates obtained from the tool and correlated to the discrimination level and VQI reinforces the common understanding that higher quality video generally requires higher bitrates.

Bitrate is the common parameter indicating both video quality and network resource requirements. In order to improve the video design process, the entire video system has to be considered. The video quality requirements and the demand for competing resources must be balanced with limited network capacity. A systematic approach to solving the challenges of delivering video over a wireless network is needed. As a result, a framework consisting of MISSION, CONTENT and TRANSPORT NETWORK (MCTn) is proposed (Sections 7.1, 7.2).

9 RECOMMENDED NEXT STEPS

The major work done by the PSCR program and the VQiPS WG establishes the foundation for effective video design and transmission over a wireless network. This work should be leveraged and broadened to meet video quality requirements, while balancing demands on a wireless network with limited resources. To accommodate this objective, the following steps are recommended:

1) Continue to refine the Video Design Improvement Process around the MCTn concept and harmonize this effort with the *Video over LTE: Efficient Network Utilization* Task. Further clarify how video system component/software design choices affect the quality of

the video output and wireless resources required. Seek appropriate input from the VQiPS leadership team and PSCR program staff.

2) Given the importance of bitrate to video quality and LTE bandwidth requirements, additional testing and examination of the trade-offs is in order. Explore capabilities at JHU/APL, or other options, for conducting video quality assessment and network bandwidth impact in a laboratory environment. Additionally, investigate advanced coding technologies and determine their benefits for video quality and network requirements.

3) Many of the use cases cited in this report give examples of video acquired by handheld wireless devices in the field and sharing that video with others. Consequently, examination of the impacts, including video quality, of using these devices as video sources on the NPSBN is warranted.

This report included relevant background information on the video quality design requirements. These requirements were presented in the context of providing the information necessary to achieve the goal of providing first responders with the video quality they need while maintaining sufficient wireless bandwidth capacity. The NPSTC *Public Safety Communications Assessment* [1] proposed three generic terms for different video quality levels (low, medium and high) in order to meet this goal. However, these generic video quality requirements were not sufficiently quantified in light of recent research efforts, so there is a need to extend these requirements. This report described a process for doing so by using general use classes of use cases and by identifying values for key parameters (target size, motion, lighting level, usage, discrimination level, frame rate, etc.) that would equate to high/medium/low quality as transmitted over the NPSBN. In addition, this report included the above recommendations for future areas of study to help fill any gaps in this process. The public safety community needs to determine what would be the next best step for research in light of these results and recent technological advancement in both codec standards and video hardware capabilities since the initial PSCR research.

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