(camera, n.d.)

VIDEO PRIVACY FOR PUBLIC IP CAMERA

A Masters Project

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Abstract

This project explores the various aspects of video privacy for public IP cameras. The data traffic of public cameras under various situations were monitored and stored. Using this, the variation of bandwidth with movement and CODECs was analyzed. Other experiments were also conducted to study the variation of bandwidth to detect the presence of a person in an indoor scenario.

Acknowledgements

I would like to thank Prof. Kui Ren for his support and guidance throughout this project and the Department of Computer Science and Engineering for giving me this opportunity. I would also like to thank Mr. Si Chen and Mr. Muyuan Li of the Department of Computer Science and Engineering for all their guidance and help throughout this project. This project would not have been feasible without the free network protocol analyser – Wireshark™ (Wireshark, n.d.). I would also like to acknowledge the creators of this truly masterpiece of a software, that's compatible to all platforms.

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Introduction

The project focuses on analyzing the video privacy of public IP Cameras. This is done by analyzing the network bandwidth of some public IP Cameras obtained from data traffic, captured using the network protocol analyzer tool Wireshark™.This bandwidth is measured under a number of experiments formulated specifically to understand how movement in the video stream of an IP Camera changes its bandwidth. The average, minimum and maximum bandwidth during these experiments were also calculated. Other experiments were conducted in order to compare how the different CODECs of these video streams are sensitive to movement. Also, in an indoor scenario, how the bandwidth can be used to detect the presence of someone was analyzed.

Background

Public IP Camera

IP cameras are those digital video cameras that send and receive data through the Internet. They are mainly used for property surveillance. (IP camera, 2015) Some of these cameras have publically assessable live streams hosted at a particular IP address on the Internet that can be used to monitor them from any part of the world at any time of the day (World Wide Livecams, n.d.) (webcamxp, n.d.). These were the kind of cameras that were used in this project. Most of these camera streams specified the model/band of the camera used and also specified the location of these cameras in the world.

Bandwidth vs Throughput

In general, Bandwidth is the theoretical maximum amount of data that can be send through a channel while throughput is the actual measure of the amount of data sent through the channel. Bandwidth is limited by network traffic, protocol used among other factors (Throughput and Bandwidth Difference?, n.d.). Hence, throughput the project both these terms are used interchangeably.

CODECs

The CODEC of a camera define the different video compression formats used by it and they vary in quality and capability. The CODECs of the cameras used in this project are H.264 and Motion-JPEG (M-JPEG). MJPEG or motion-JPEG sends a series of still, complete JPEG images. MPEG4 andH.264 usually send only changes between a reference or frames, which results in less bandwidth consumption and disk space. (MJPEG vs. MPEG4/H.264, n.d.)

Modes

The modes of these cameras regulate the bandwidth needed by them. In Constant Bit Rate (CBR), the quality adjusts depending on the resolution, frame rate, motion in the scene and the bitrate selected. The lower the bitrate value, the lesser is the bandwidth that gets used and hence, the video gets more compressed. In Variable Bit Rate, the quality remains constant while the bandwidth fluctuates based on the motion in the scene. H.264 streams use CBR while M-JPEG streams use VBR. (What are CBR and VBR?, n.d.)

TCP vs. UDP

After analysis of the data traffic using Wireshark™, H.264 streams seems to mostly use the UDP protocol for transfer. UDP is unreliable but is ideal for video streaming, which can tolerate small packet loss as long as the data transfer is fast. On the other hand, M-JPEG streams seems to mostly use the reliable, TCP protocol for data transfer. TCP is very reliable but has connection overhead and usually results in much slower data transfer.

H.264 vs. M-JPEG

Thus quality observed in the H.264 streams were much poorer than that of M-JPEG streams. But, H.264 streams consume much less bandwidth and storage than the equivalent quality M-JPEG. (What are the bandwidth savings of H.264 vs MJPEG?, n.d.)

Experiments

Thirty experiments were conducted on eight different IP cameras to study the video privacy of an IP camera. Once a camera was chosen, the model/band, location, IP address, supported CODECs, the mode of the operation of the cameras were found. Then the data traffic from the video streams of these cameras in the chosen scenarios were monitored and stored using Wireshark™.

Assumptions

After combing through hundreds of public IP cameras, eight different public IP Cameras across the world were chosen to monitor and store data in thirty different scenarios. Among these eight cameras, five of them were used to surveillance indoors locations and couldn't support H.264. So, all the indoor experiments were conducted using M-JPEG streams of these cameras. But the other three cameras that were used to surveillance three different outdoor locations, were found support both H.264 and M-JPEG. Hence, these were used to perform experiments to test the sensitivity of two CODECs to movements. Much of these experiments were coincidental as the movement of people in these locations were unpredictable. The camera model too determines the quality of video that was streamed other than CODECs used. Hence, the camera quality too varied in all eight locations.

Outdoor Experiments

The outdoor experiments were performed during day and night times. It was impossible to find an outdoor scenarios during the day, where no motion could be visibly detected due to the presence of trees and constant movements of people walking around these locations. So, the CODECs were only varied in these scenarios while collecting data traffic. 8 such scenarios in 3 different camera locations were observed. However, during the night, in a particular location, there were situations where no visible movement was observed, hence data traffic was collected in scenarios with and without motion along with varying CODECs. 10 scenarios were observed in this location. The 18 outdoor scenarios observed in the streams during day and night times have these variations in motion -

- Motion throughout data capture
- Motion at the beginning of data capture
- Motion at the end of data capture
- No / Slight motion during data capture
- 1 person moves at the beginning of data capture

Indoor Experiments

The 12 outdoor experiments were performed during day/night times or during an unknown time of the day in various IP camera's M-JPEG streams. The locations were usually brightly light except in one scenario. As mentioned earlier, it was difficult to find an outdoor scenario without movement. Hence all the experiments done indoor had either no/slight motion, motion at the beginning of data capture or motion throughout data capture.

Once, these data traffic were stored, Wireshark™ was used to calculate the average (htt1), maximum and minimum bandwidth along with the plot of the data received in bytes vs time in seconds. Table were then created in Microsoft Excel™ with the average bandwidth in the various scenarios to find the link between the movement in a scene and bandwidth, sensitivity of CODECs with movement and how to detect the presence of someone inside an indoor scenario. These tables can be found in the Appendix section.

Evaluation

There were a number of assumptions made while doing this project. Experimental results in these projects are purely coincidental, as we have no control over the environment of these remote public IP cameras. So, data traffic for all possible scenarios for every stream couldn't be observed. The quality of these cameras were not the same, hence the comparison made using them may not give universally true results.

Conclusion and Future Work

The major conclusion obtained from these experiments is that the bandwidth most definitely changes with movement and even seems to increase with movement(Figures 34 and 35).This is due to the fact that any movement would need a larger packet/data transfer as the pixels in the video will have to rapidly change in order to portray movement to the viewer. Also, M-JPEG streams need a larger bandwidth than a H.264 stream (Figure 33) and seem to be more susceptible to movement as it bandwidth dramatically changes(Figure 36). This is perhaps because it uses the VBR mode. In the case of indoor scenarios (Figure 37) however, the presence or absence of a living being seems to definitely change the bandwidth but it might be an increase or decrease. A living being in any room is prone to undergo at least some slight movements as there is always the need to breathe and might move a little in the process. In some indoor scenarios, a slight movement seems to increase the bandwidth when compared to a motion throughout scenario while in others, it seems to decrease when compared to a no motion scenario. Hence if this increase or decrease (depending on the initial environment) could be used to detect if a person is inside a room.

But, because of a number of assumptions made in this project, no universally true conclusions can be made on the privacy of public IP cameras except that it's rather easy to spy using them and movement in their streams definitely affects the bandwidth, which could be exploited. A more concrete approach to obtain better results would be where we have control over the environment in which the IP camera exists and perform more time-controlled experiments to see bandwidth variations in the data traffic captured. We could also use motion detection algorithms to increase efficiency.

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Appendix

CBR vs. VBR

The constant bit rate can be observed in the H.264 stream of an outdoor scenario.

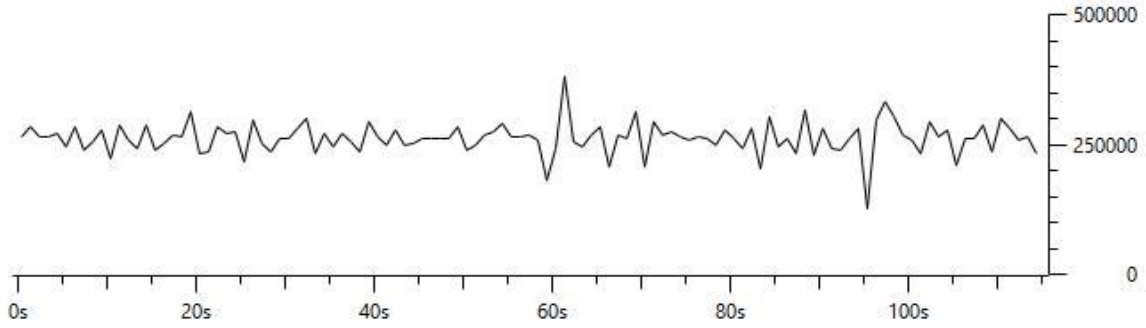

Figure 1 Data received (in Bytes) vs. Time for an outdoor M-JPEG stream.

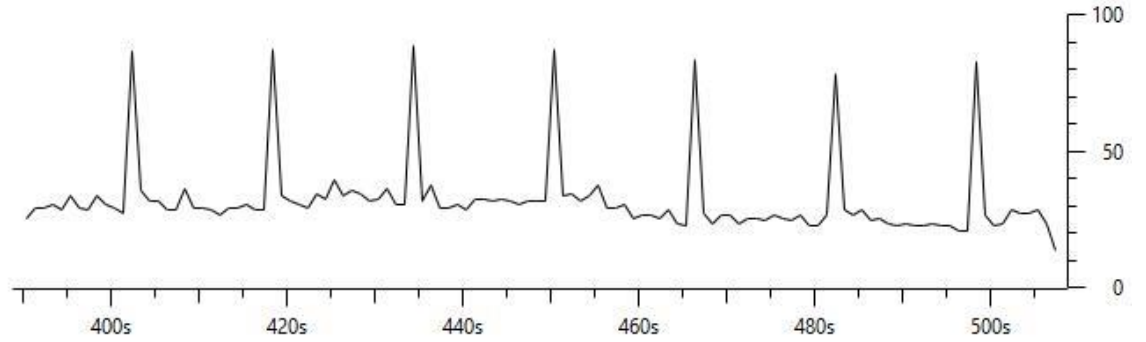

Figure 2 Data received (in Bytes) vs. Time for an outdoor H.264 stream.

Target 0

Camera No.	Model/Band	Location	Type	IP Address	CODECs	Protocol	CBR/VBR
1	AXIS P1344 Network Camera	Oregan State University - Trackfield	Outdoor	128.193.182.123	H.264/MJPEG	UDP/TCP	CBR/VBR
2	AXIS P1346 Network Camera	Duke University - Plaza	Outdoor	152.3.16.13	H.264/MJPEG	UDP/TCP	CBR/VBR
3	AXIS M1011-W Network Camera	Unknown Room	Indoor	208.42.203.54	MJPEG	TCP	VBR
4	AXIS 212 PTZ Network Camera	Alfred University	Indoor	149.84.160.250	MJPEG	TCP	VBR
5	AXIS Q6034-E Network Camera	Skyview Madera	Outdoor	50.73.56.89	MJPEG/H.264	TCP/UDP	VBR/CBR
6	AXIS M1031-W Network Camera	AMAKS Hotels and Resorts	Indoor	94.232.8.10	MJPEG	TCP	VBR
7	AXIS M1054 Network Camera	M&DH Insurance Services	Indoor	81.142.19.65	MJPEG	TCP	VBR
8	Panasonic Web Camera	Unknown Room in Schweiz	Indoor	193.138.213.169	MJPEG	TCP	VBR

Table 1 The IP Cameras used with their model/band, location, IP address, CODECs, Modes, and Protocol used.

Target 1

Note – Many of the plots do not show the entire span of time during which data traffic was captured.

Alfred University

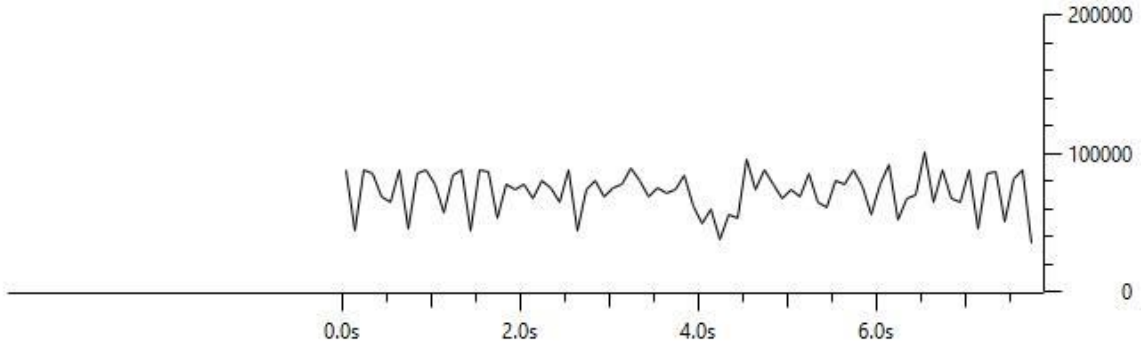

Figure 3 Alfred University - Motion at the Beginning

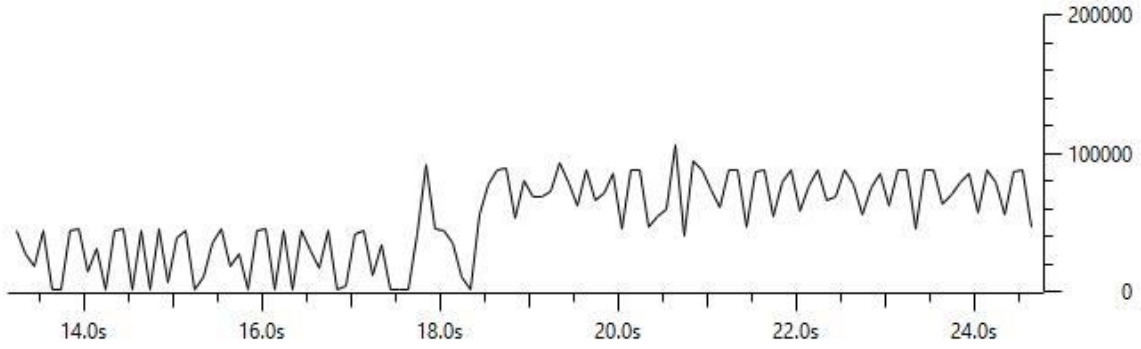

Figure 4 Alfred University - Motion throughout

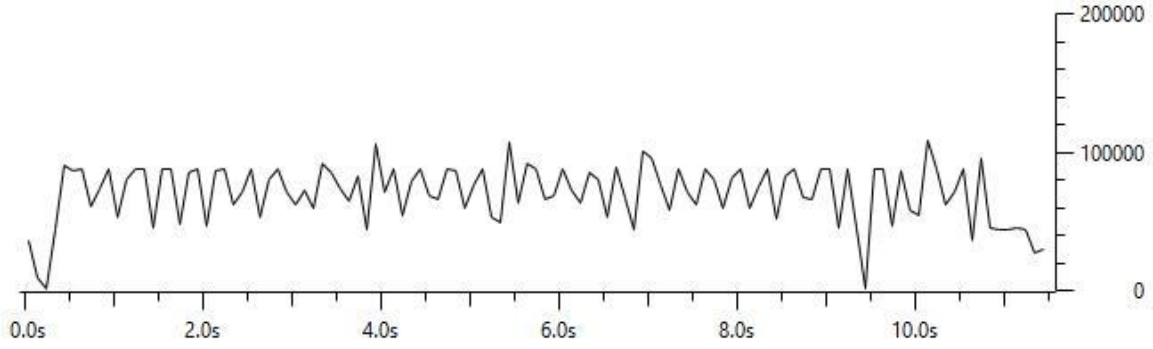

Figure 5 Alfred University - No or slight motion

Unknown Room

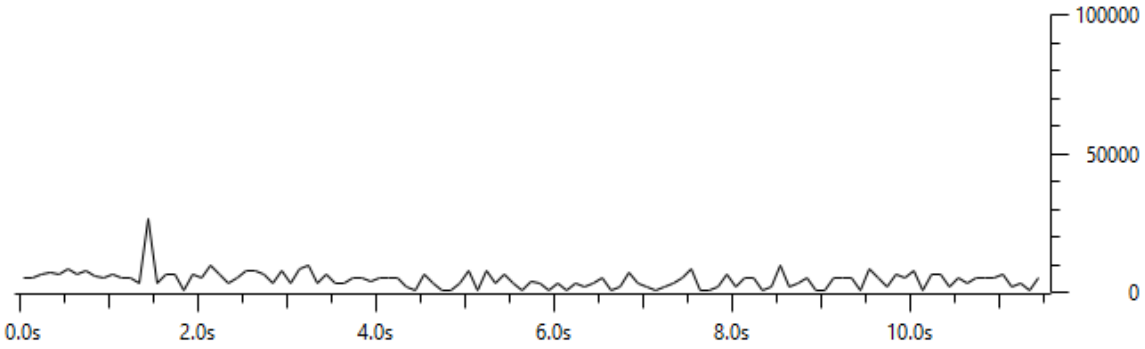

Figure 6 Unknown Room - Motion Throughout

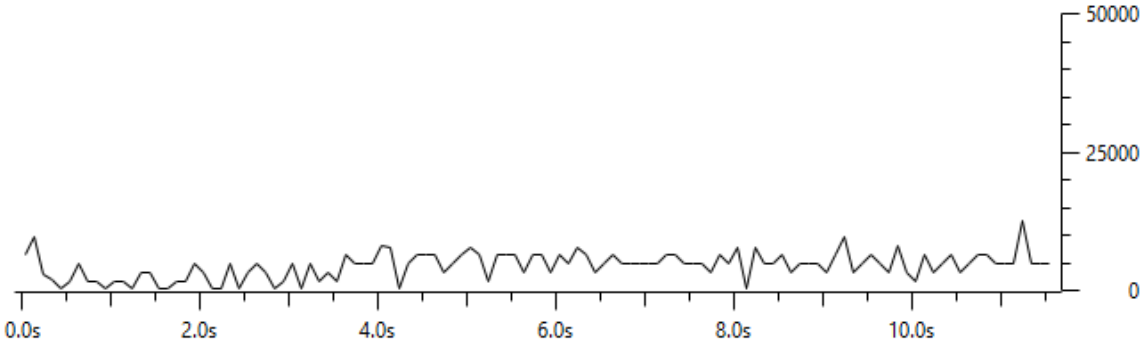

Figure 7 Unknown Room - No/Slight Motion

Duke University – During the Day

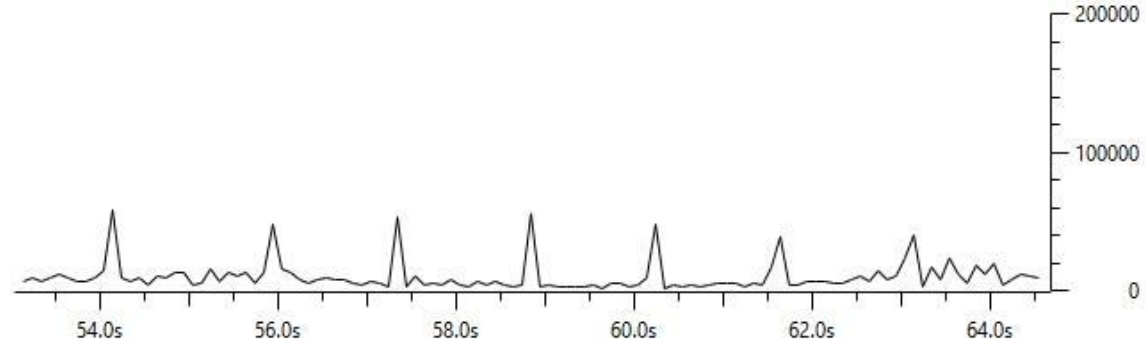

Figure 8 Duke University during the Day - Motion Throughout - H.264 stream

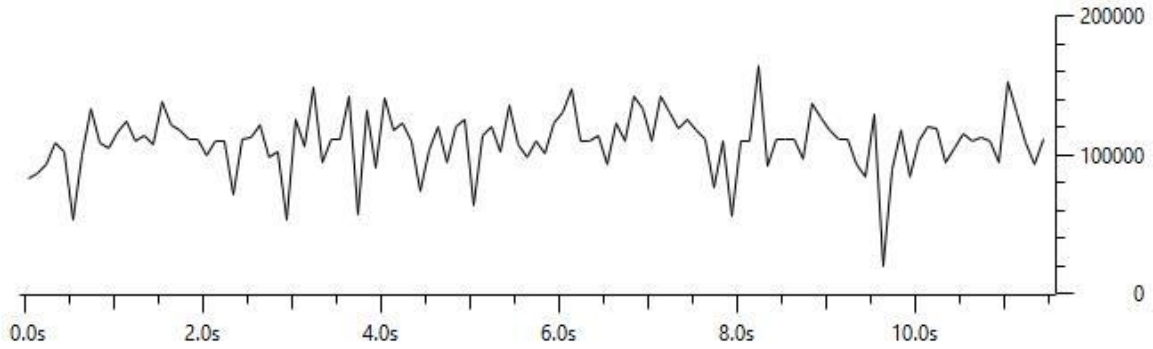

Figure 9 Duke University during the Day - Motion Throughout - M-JPEG stream

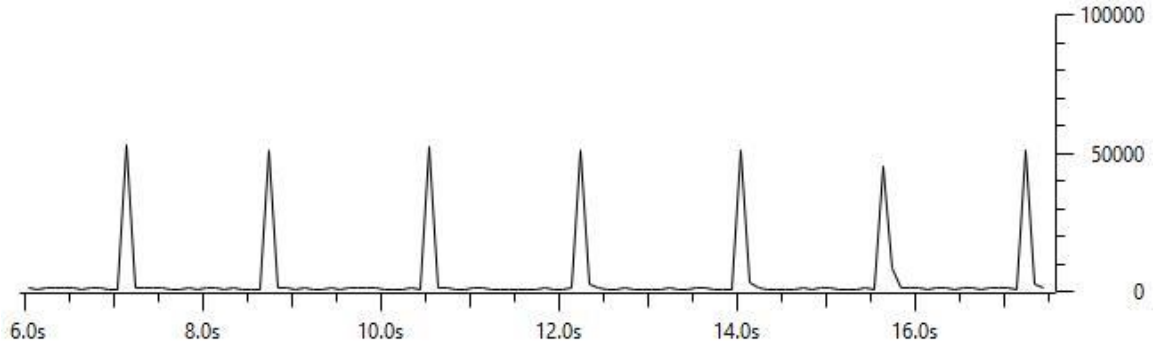

Figure 10 Duke University during the Day - Slight Motion - H.264 stream

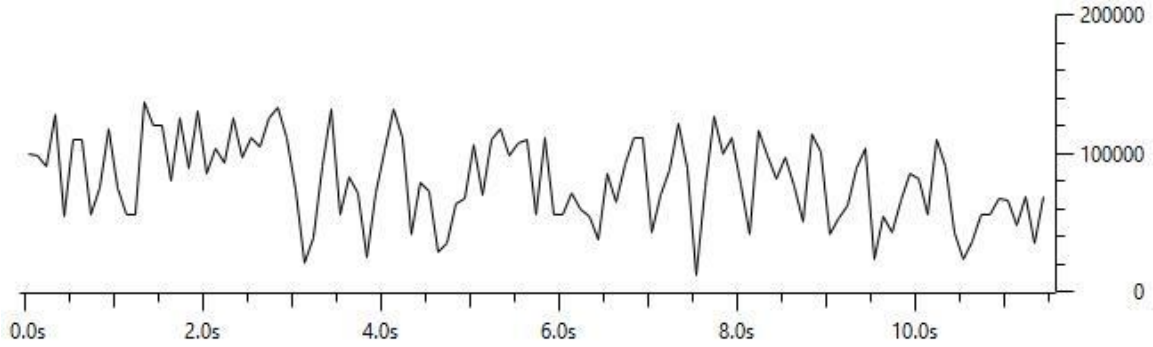

Figure 11 Duke University during the Day - Slight Motion - M-JPEG stream

Duke University – At Night

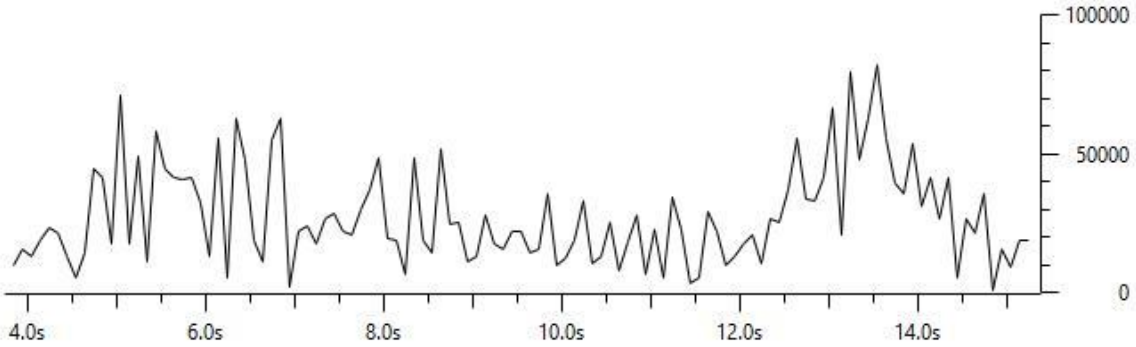

Figure 12 Duke University at Night - Motion at the beginning - M-JPEG stream

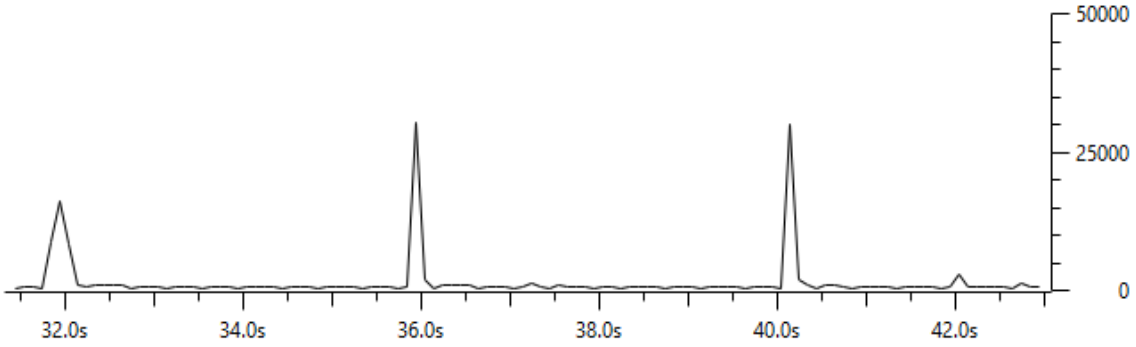

Figure 13 Duke University at Night - Motion at the beginning - H.264 stream

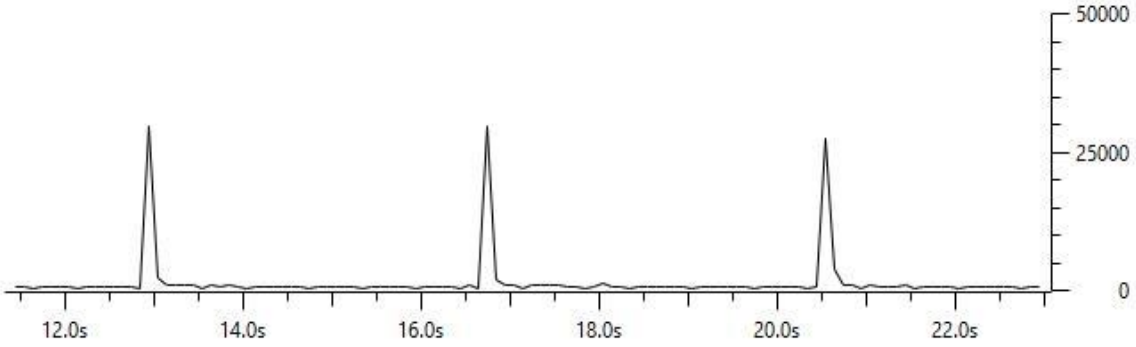

Figure 14 Duke University at Night – One person moves at the beginning - H.264 stream

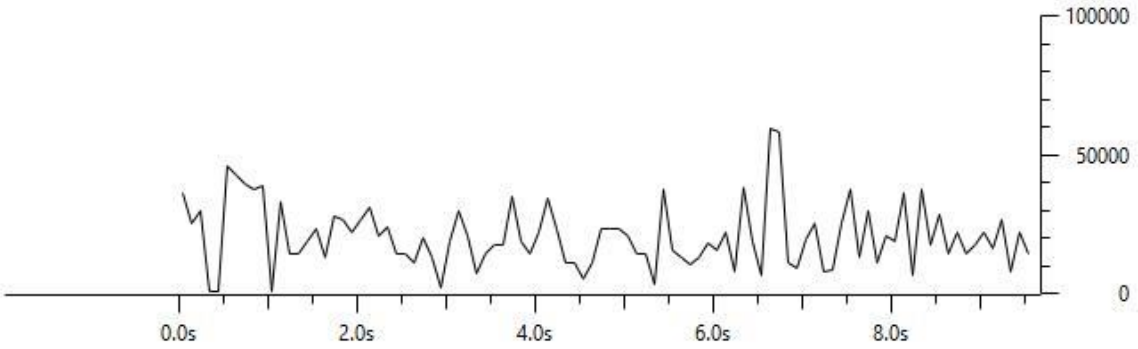

Figure 15 Duke University at Night – One person moves at the beginning - M-JPEG stream

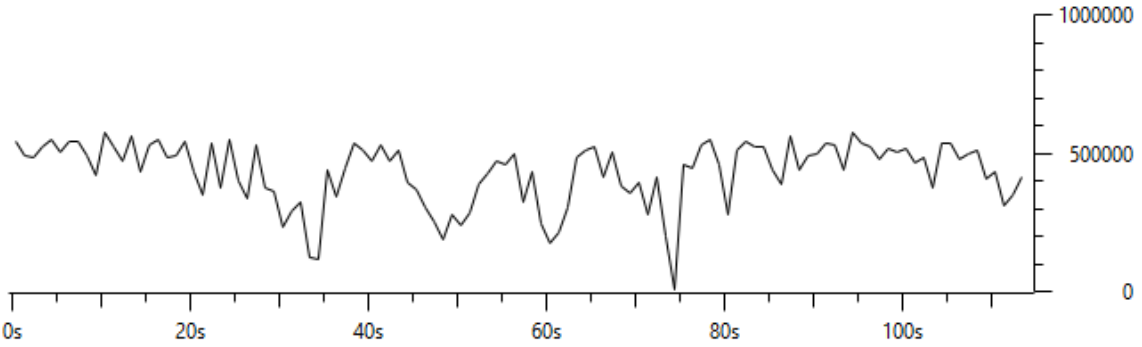

Figure 16 Duke University at Night – Motion at the end - M-JPEG stream

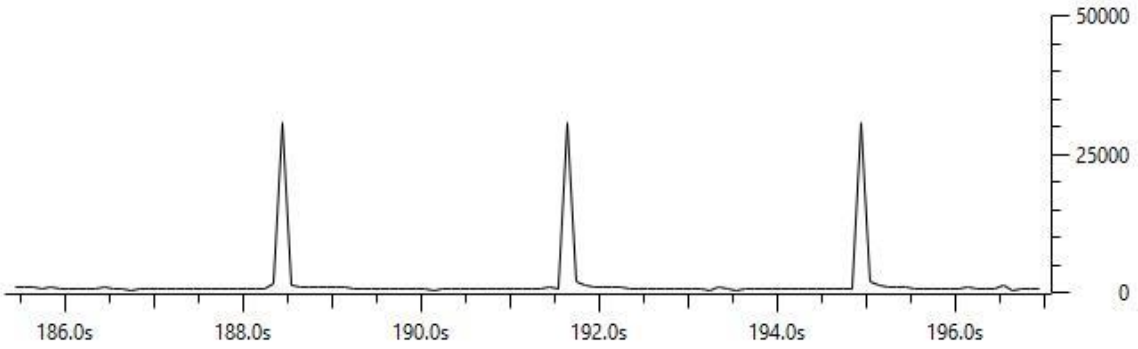

Figure 17 Duke University at Night – Motion at the end - H.264 stream

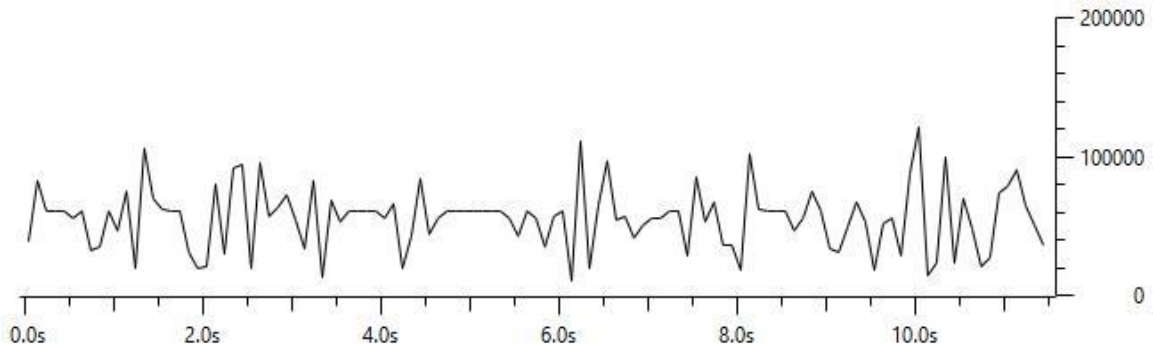

Figure 18 Duke University at Night – Motion throughout - M-JPEG stream

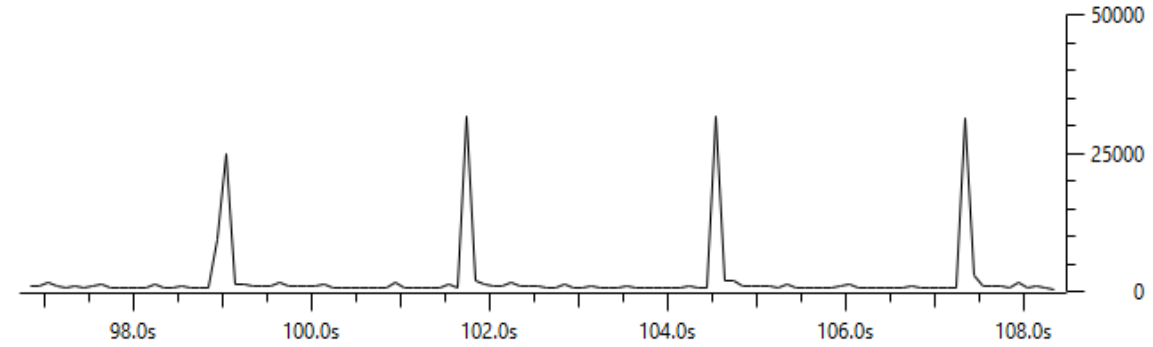

Figure 19 Duke University at Night – Motion throughout - H.264 stream

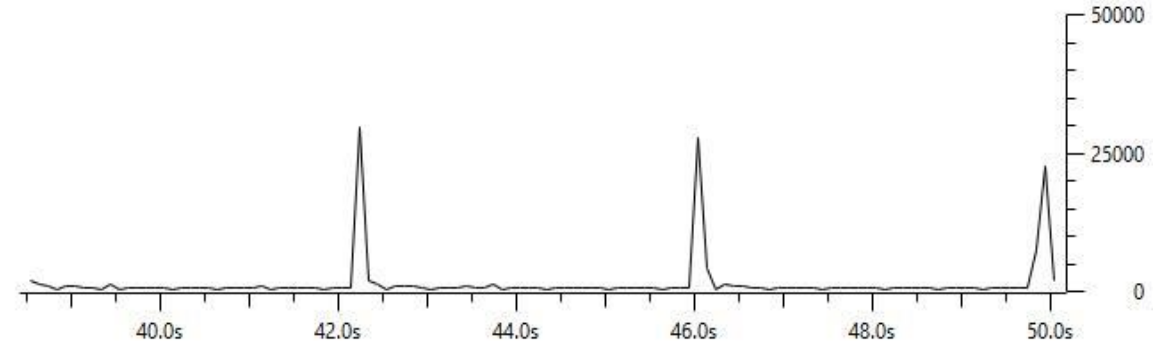

Figure 20 Duke University at Night –No Motion - H.264 stream

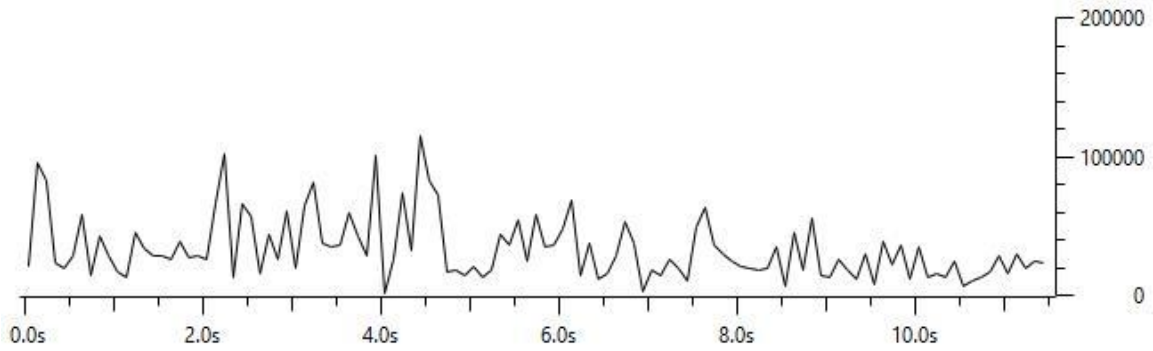

Figure 21 Duke University at Night –No Motion - M-JPEG stream

Skyview Madera

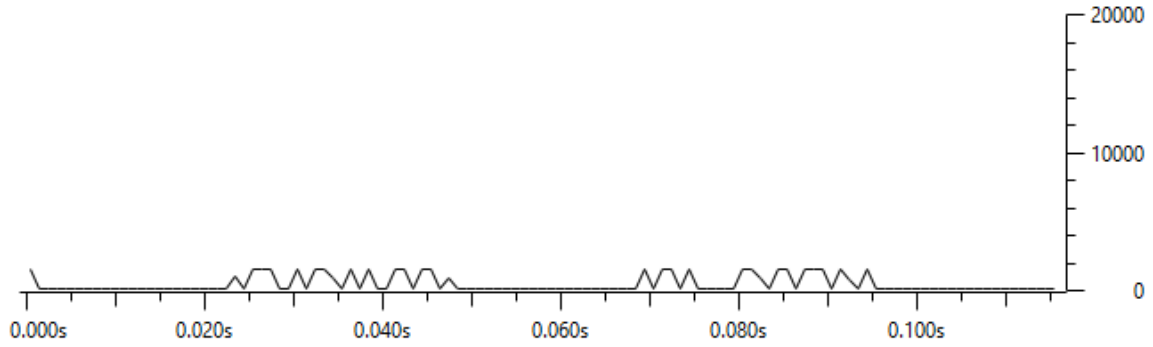

Figure 22 Skyview Madera – H.264 stream

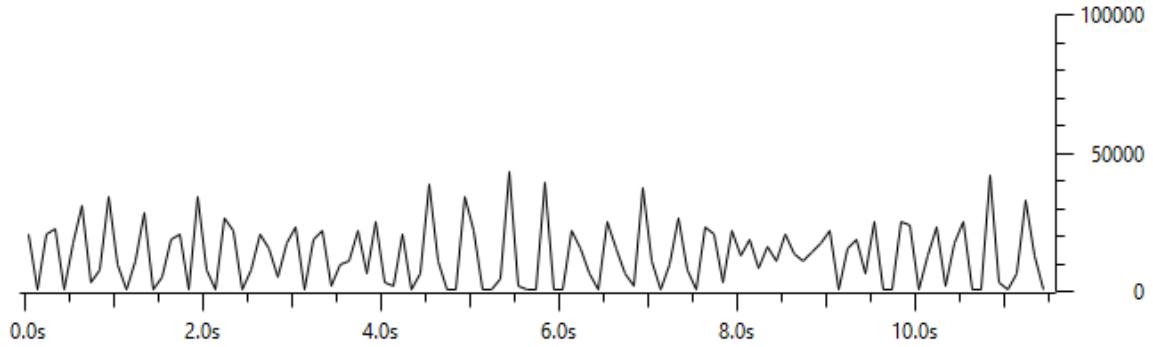

Figure 23 Skyview Madera – M-JPEG stream

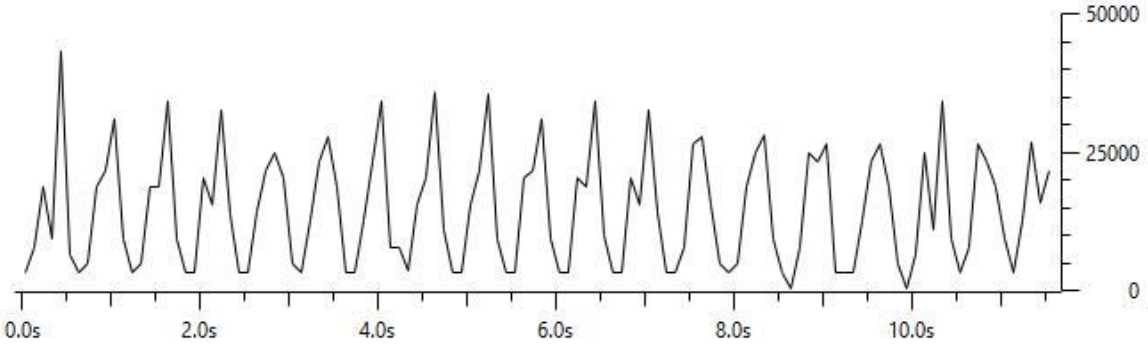

Figure 24 AMAKS Hotels and Resorts - Motion Throughout

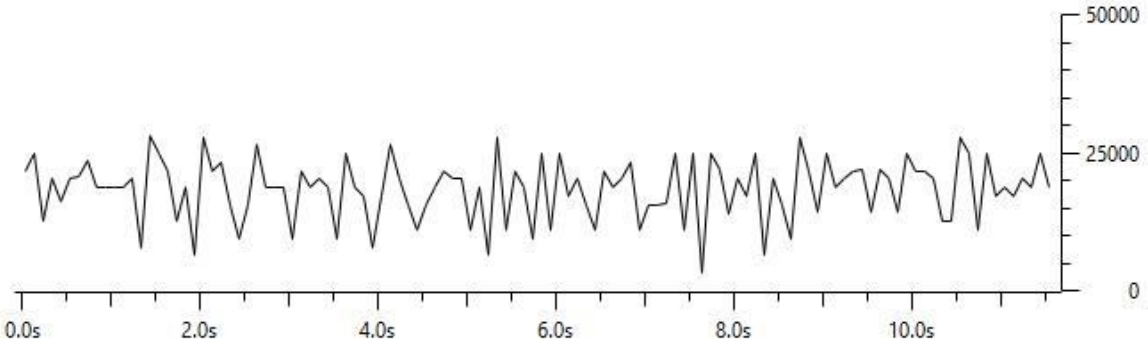

Figure 25 AMAKS Hotels and Resorts - No Motion

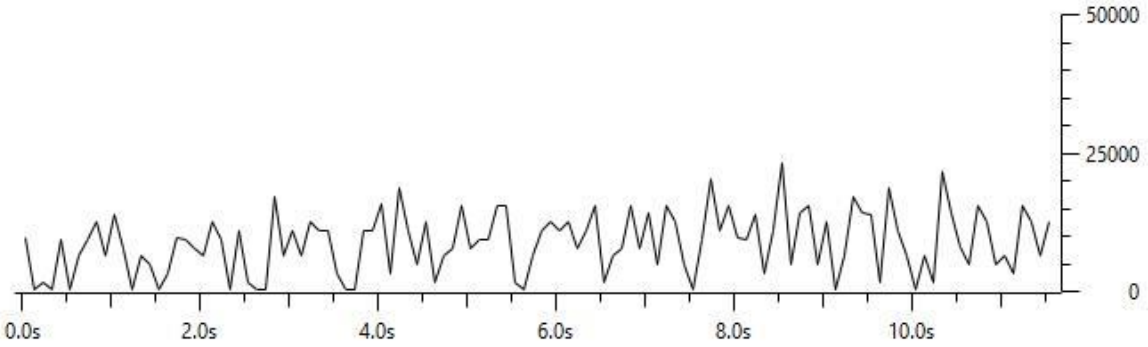

Figure 26 AMAKS Hotels and Resorts – Slight Motion

M&DH Insurance Services

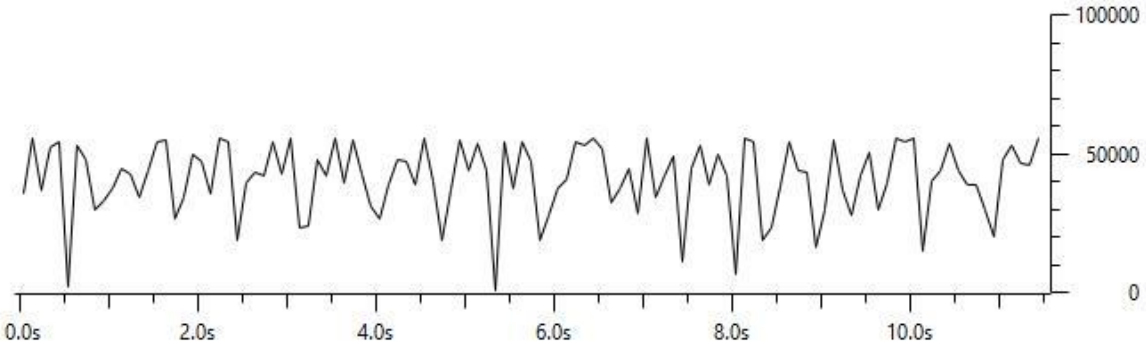

Figure 27 M&DH Insurance Services - No motion

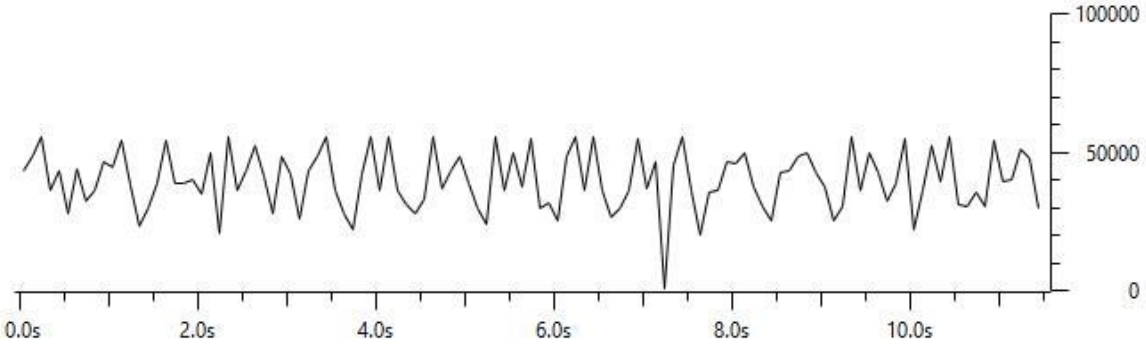

Figure 28 M&DH Insurance Services - Slight motion

Oregon State University – Trackfield

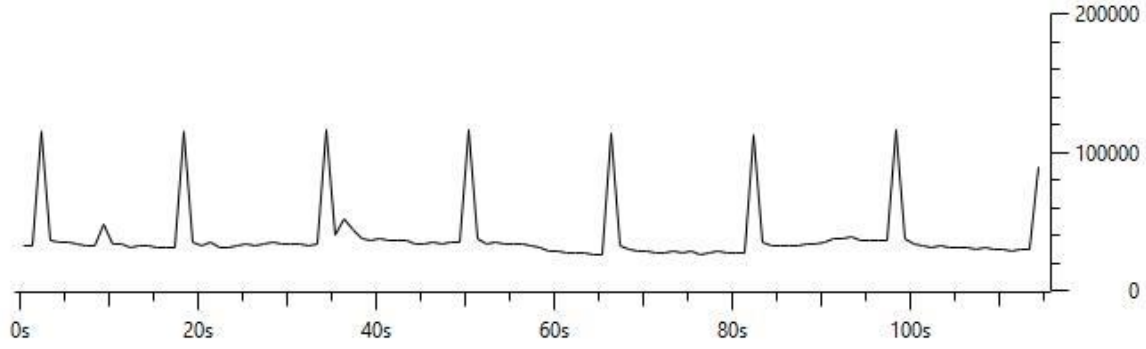

Figure 29 Oregon State University – Motion throughout - H.264 stream

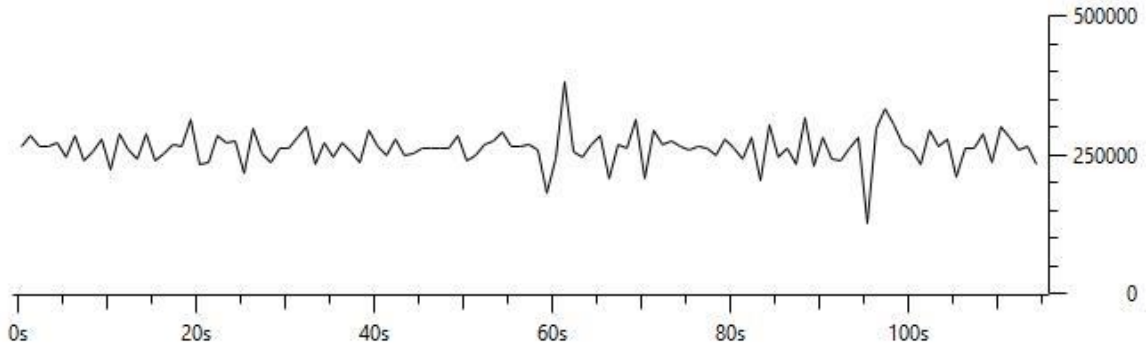

Figure 30 Oregon State University – Motion throughout - M-JPEG stream

Unknown Room in Schweiz

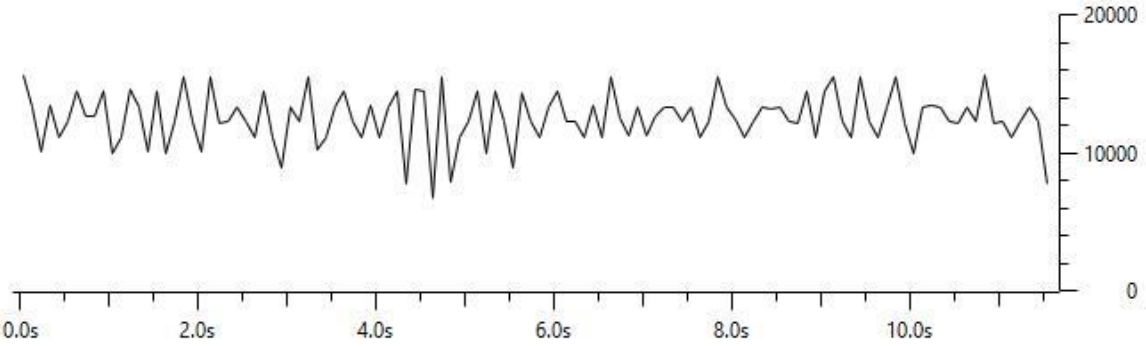

Figure 31 Unknown Room in Schweiz - Motion throughout

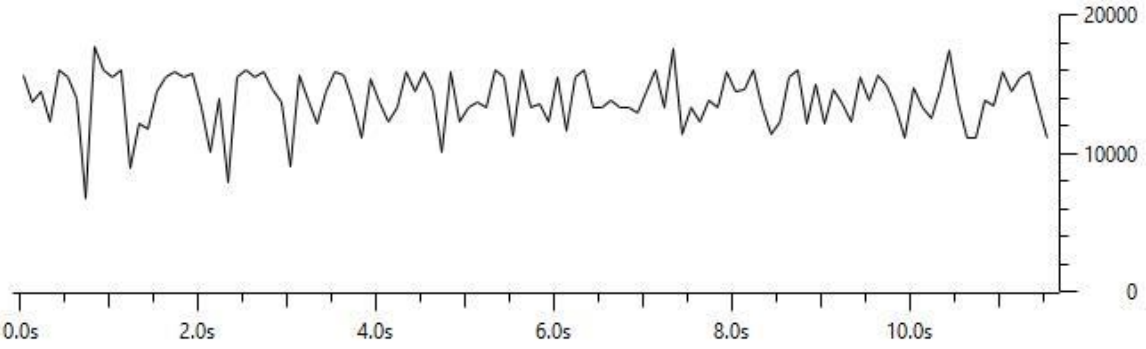

Figure 32 Unknown Room in Schweiz -No Motion

Target 2

Table 2 Average/Max/Min Bandwidth

Scenario No.	Location	Time of the Day/Lighting	CODECs available	Scenario	Avg BW (Mbps)	Max BW	Min BW
1	Oregan State University -Trackfield	Day/Bright	H.264	Motion	2.071	7.00531	0.003138
2			MJPEG	Motion	0.305	34.59302	2.10E-02
3	Duke University - Plaza	Day/Bright	H.264	Motion	0.809	19.31152	0
4			MJPEG	Motion	8.659	104.7278	0.003645
5			H.264	Slight Motion	0.3	2.542589	0.000848
6			MJPEG	Slight Motion	6.122	118.877	0.128622
7		Night/Dark	H.264	Motion at the beginning	0.118	2.122803	0
8			MJPEG	Motion at the beginning	2.278	4.818115	0
9			H.264	Motion at the end	0.129	2.0676	0
10			MJPEG	Motion at the end	3.439	59.22266	0
11			H.264	Motion	0.158	3.46344	0
12			MJPEG	Motion	4.262	100.4224	0
13			H.264	No Motion	0.101	13.2019	0
14			MJPEG	No Motion	3.033	116.0461	0
15			H.264	1 person moves at the beginning	0.098	2.567487	0
16			MJPEG	1 person moves at the beginning	1.549	30.09677	0
17	Unknown Room	Unknown/Bright	MJPEG	No / Slight Motion	0.502	11.5918	0
18		Unknown/Bright	MJPEG	Motion	0.315	5.67627	0
19	Alfred University	Day/Bright	MJPEG	Motion at the beginning	5.744	53.02368	1.006923
20			MJPEG	No / Slight Motion	4.197	27.41852	0
21			MJPEG	Motion	3.213	76.01685	0
22	Skyview Madera	Day/Bright	MJPEG	Motion	1.049	12.23633	0
23			H.264	Motion	2.677	33.6377	0
24	AMAKS Hotels and Resorts	Unknown/Bright	MJPEG	No Motion	1.399	30.09766	0.045056
25			MJPEG	Slight Motion	0.751	2.821655	0
26			MJPEG	Motion	0.984	13.16772	0
27	M&DH Insurance Services	Unknown/Dark	MJPEG	No Motion	3.105	67.41943	0
28		Unknown/Bright	MJPEG	Slight Motion	2.925	58.48755	0
29	Unknown Room in Schweiz	Day/Bright	MJPEG	No Motion	1.077	16.5564	0.00054
30		Night/Bright	MJPEG	Motion	0.99	16.18652	0.043049

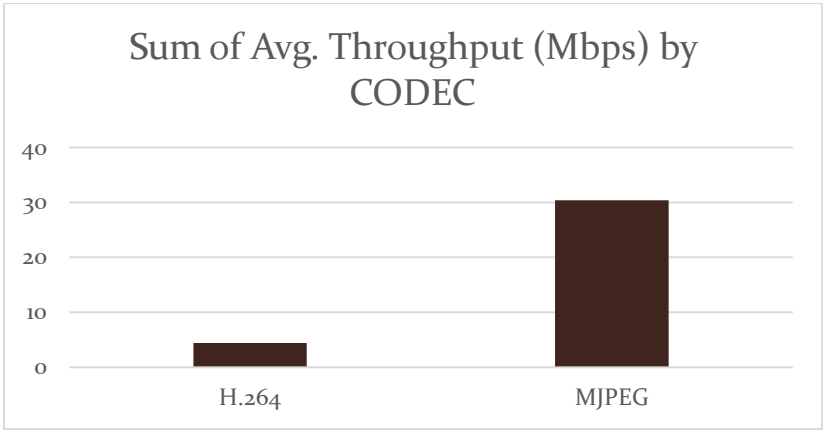

Figure 33 CODEC throughput comparison

Target 3

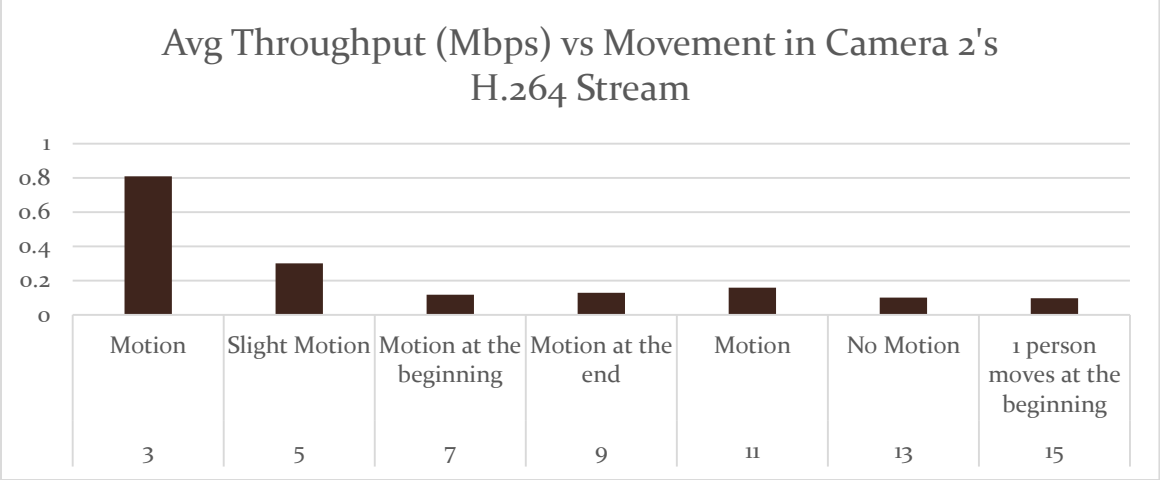

Figure 34 Avg. Throughput vs Movement in a H.264 stream

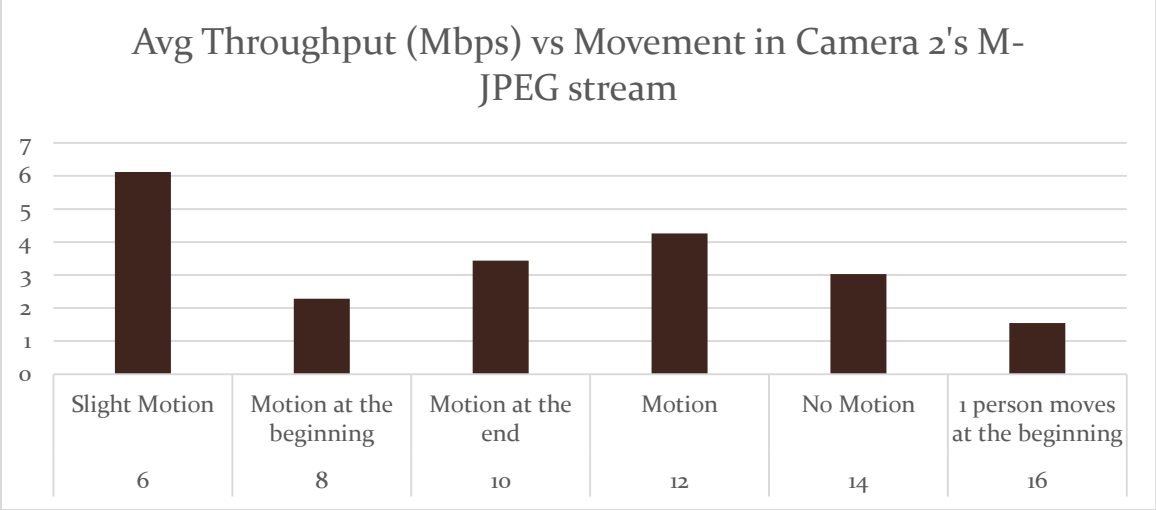

Figure 35 Throughput vs Movement in a JPEG stream

Target 4

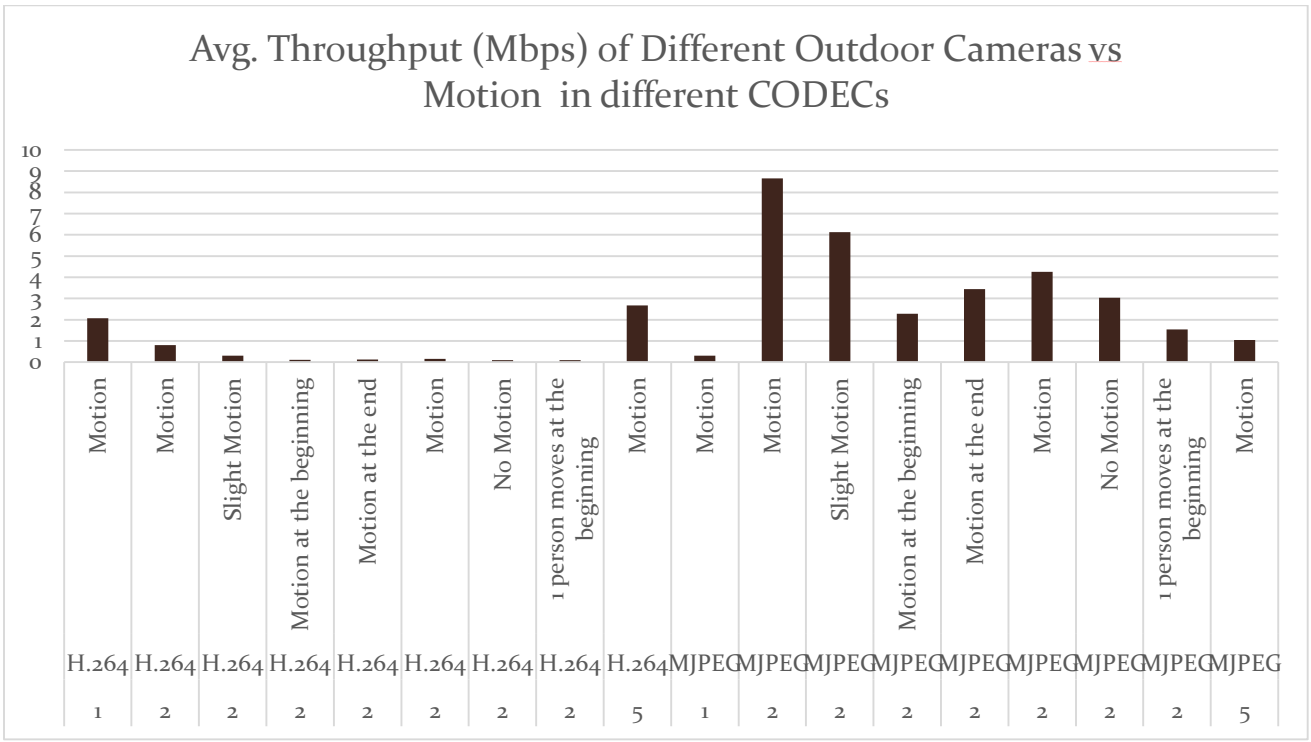

Figure 36 Avg. Throughput of different outdoor cameras vs motion in different CODECs

Target 5

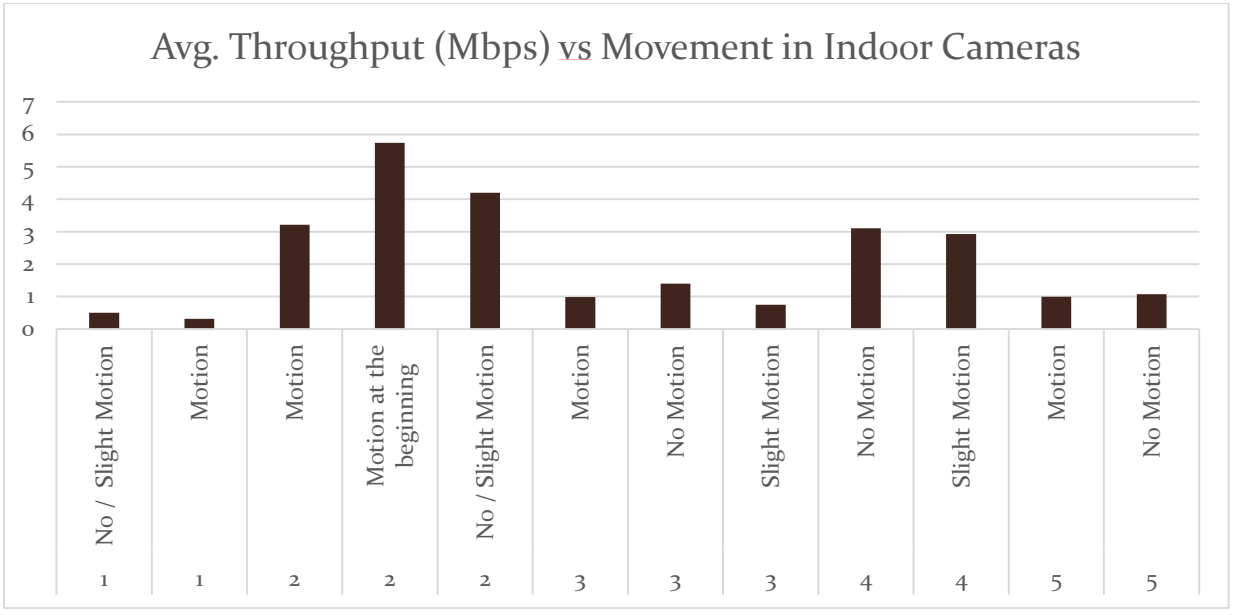

Figure 37 Average Throughput vs Movement in Indoor Cameras

Where 1- Camera No. 3, 2- Camera No. 4, 3- Camera No. 6, 4- Camera No. 7, 5- Camera No. 8