WHITE PAPER

Maximizing IoT Edge Processing

Reducing cloud costs with Intel® Core™ processor-based gateways

Introduction

The world is in the midst of a dramatic technological transformation that will have far-reaching impacts for almost all aspects of life. We are going from primarily utilizing isolated computer systems to employing smaller, specialized Internet-enabled "things." These devices are capable of generating data and communicating with each other and with the cloud. Commonly referred to as the Internet of Things (IoT), this technology allows almost any organization to create customized networks of connected devices that can transform business operations, conserve energy, improve factory productivity, and enrich the effectiveness of nearly every activity imaginable.

However, there is a great deal that needs to be accomplished to realize this vision. Nearly 85 percent of existing things were never designed to connect to the Internet and cannot share data with the cloud.[1] At the same time, if all these things were connected to the cloud, it would produce more data than the entire world's cloud resources could handle.

Intel's solution to managing these problems is the Intel® IoT Gateway. This platform can connect legacy and new systems, perform local data processing, and enable seamless and secure data flow between edge devices and the cloud (Figure 1).

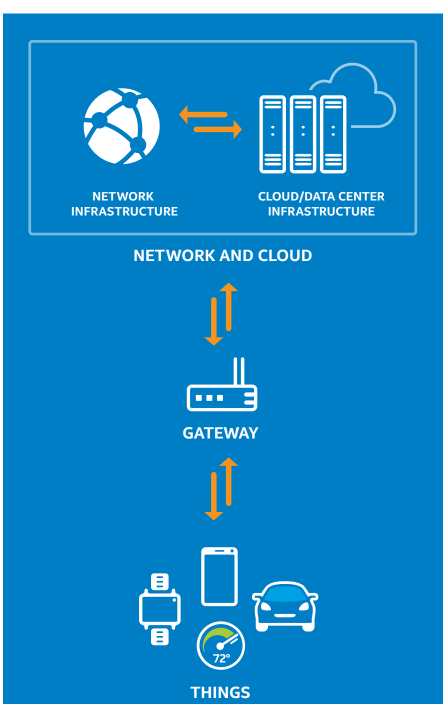

Figure 1. Intel® IoT Gateway solutions connect things to the cloud.

In this paper we will examine the role IoT gateways play at the edge and how they can save businesses money in their day-to-day operations. We'll also look at recent tests that show how these gateways are even more effective when based on Intel® Core™ i7 processors compared to Intel® Atom™ processors in simulations of real-world applications. Specifically, these tests demonstrate the following advantages for Intel IoT Gateway-based solutions with Intel® Core™ processors:

- In motion and face detection, the Intel Core processor-based gateways handle more video streams and thus allow more cameras per gateway and fewer gateways per installation.
- For packet processing and filtering, the Intel Core processor-based gateways handle greater workloads, allowing deployment of fewer gateways at the edge to do the same amount of work.
- Placing greater compute capacity at the edge is an excellent strategy for reducing network traffic and cloud-computing costs.

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Building Out the Internet of Things

To help solution builders scale out the IoT, in December 2014 Intel introduced the Intel® IoT Platform (Figure 2). This end-to-end reference model includes Intel IoT Gateways as a key part of a family of solutions from Intel and the industry. The platform provides a foundation for seamlessly and securely connecting devices, communicating trusted data to the cloud, and delivering value through analytics.

The Intel IoT Platform can help solution providers deliver innovations to market faster. It reduces solution complexity and delivers actionable intelligence by offering a defined, repeatable foundation for how things connect and deliver data to the cloud.

Essential capabilities of the Intel IoT Platform model include:

- Connecting the unconnected
- Data and device management
- End-to-end security
- Unlocking the value of data
- Visualizing data and monetizing insight

Intel IoT Gateway

Solutions built on the Intel IoT Gateway, such as the ones pictured in Figure 3, are a critical part of the Intel IoT Platform. With billions of things still unconnected and the Internet full of security threats, these gateways perform the essential functions of securely connecting legacy and new devices, gathering data, providing intelligence at the edge, enabling remote management, and performing local analysis and control functions.

Intel IoT Gateway-based solutions are application-ready and scalable through a range of Intel® processors, including Intel® Quark™ SoCs, Intel Atom processors, and Intel Core processors. The scalability and flexibility of the architecture enables matching the

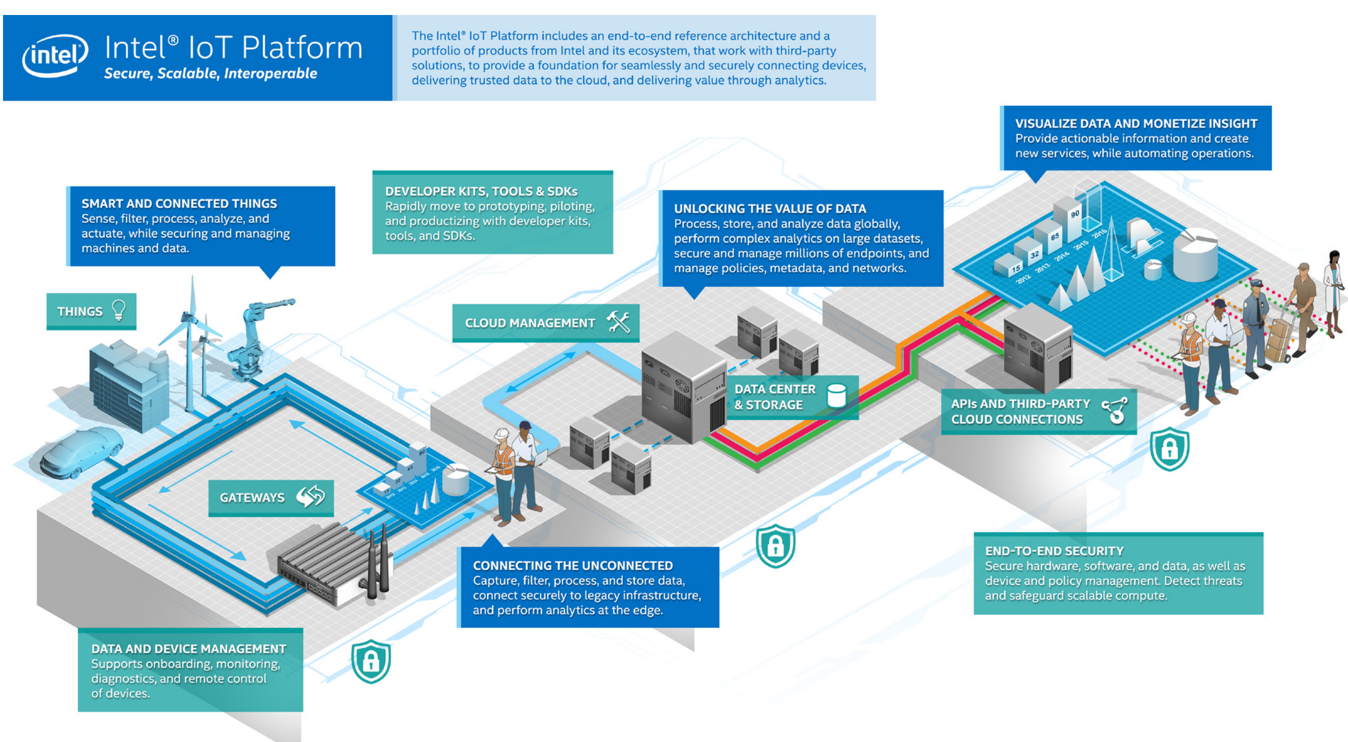


Figure 2. The Intel® IoT Platform: an end-to-end reference model encompassing a family of solutions.

Figure 3. Solutions built on the Intel® IoT Gateway are an essential ingredient of the Intel® IoT Platform and are available in a range of scalable form factors based on Intel® processors.

gateway to the workload, as well as scaling to meet evolving needs. The gateways support popular operating systems from Wind River, Microsoft, and Canonical (Snappy Ubuntu Core*).

Intel IoT Gateway solutions play key roles in collecting and processing data for such use cases as:

- Energy monitoring for homes and buildings
- Data and packet filtering for telecom and energy applications
- Local video analysis for digital surveillance solutions
- Environmental monitoring and control for cities
- Predictive analytics and machine learning for manufacturing
- Predictive maintenance for fleet management

The Need for Compute-Enabled Intelligence at the Edge

The number of businesses using IoT solutions day-to-day is increasing rapidly. IoT is playing key roles in retail, industrial automation, energy, transportation, healthcare, and many other markets, and each new solution increases the number of devices connected to the cloud. These connections are contributing to an exponential increase in the amount of data being generated and transmitted.

Currently, far less than one percent of data generated by things is captured, filtered, and transmitted to the cloud. This still amounts to an incredible quantity of data. And this quantity is growing. According an IDC report, "2015 Mid-Year Review of the Internet Things," the number of IoT end points added per minute will increase from 4,500 in 2015 to more than 7,900 in 2020 (Figure 4). This would be 474,000 end points per hour, 11.4 million end points per day, or 4 billion end points in a year. If each of these end points generated 64 bytes per second, the total data that would need to be transmitted would be about 266 Gb/s. That's enough to fill a 1 TB drive every four seconds.

With so many end points creating data, trying to transfer, store, and process these massive quantities of data in the cloud will be immensely expensive. So what's the solution?

IoT Edge Processing

The most effective way to reduce data transmission to the cloud is to process more data at the edge. This not only reduces network traffic and cloud costs, but it also spurs the creation of new edge services and revenue streams.

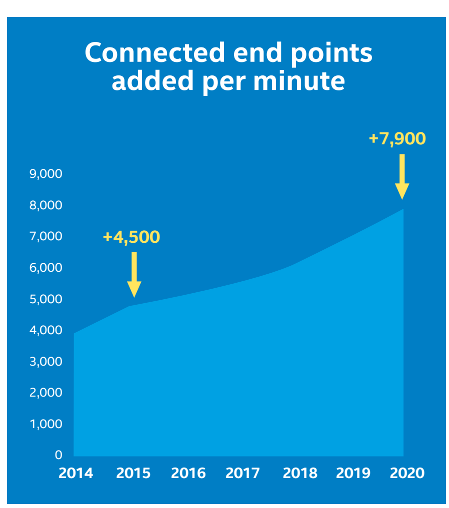


Figure 4. Growth in the number of IoT end points added per minute.

Intel offers scalable IoT gateway technology designed to bring data processing to the edge, including new Intel Core processor-based gateways that provide a leap forward in the amount of local processing that can be accomplished, and in the analytic workloads that a given gateway can handle. These new, more powerful gateways allow businesses to analyze and act upon more edge information in near real time while reserving more robust cloud and datacenter analysis for enterprise-wide applications.

Solutions for dividing processing between the cloud and gateway-level devices are already available. Once an enterprise implements powerful compute capabilities at the edge it will be able to view and act on larger volumes of data than is currently possible without incurring excessive cloud costs.

How much could be saved? Depending on the application, solutions using Intel IoT Gateways with Intel Core processors could handle as much as 99 percent of the processing locally. According to Gigaom Research, a typical cloud service charges 10 cents per 1 GB of upload and 15 cents per 1 GB of download. Uploading 1 petabyte (equivalent to 1 million gigabytes, and not uncommon for large enterprises) would cost USD 100,000. A network of Intel® processor-based gateways processing 99 percent of the data locally could save an enterprise up to USD 99,000 per petabyte of data produced.

TABLE 1. PROCESSOR FEATURE COMPARISON CHART

FEATURE	INTEL® ATOM™ PROCESSOR E3826	INTEL® CORE™ I7-4700EQ PROCESSOR	PERFORMANCE ADVANTAGE
Intel® Hyper-Threading Technology	No	Yes	Two threads per core instead of one can up to double the processing speed for many applications.
Intel® Turbo Boost Technology 2.0	No	Yes	Dynamic performance and power control enable timely performance boosts and power savings.
Processor Base Frequency	1.46 GHz	2.4 GHz, with ability to ramp up to 3.4 GHz for short periods of time	Faster base frequencies enable faster processing.
CPU Cache	1 MB L2 Cache	6 MB Intel® Smart Cache	CPU cache is fast memory located on the processor for quick access to data. Intel® Smart Cache allows all cores to dynamically share access to last-level cache. The combination of a larger cache size and dynamic sharing enables faster access to a greater quantity of the most-needed data to perform a task.
Maximum Memory Support	8 GB	32 GB	Greater amounts of system memory allow more data and applications to be held in memory for faster access and completion of tasks.
Instruction Set Extensions	No	Streaming SIMD Extensions 4.1/4.2 and Intel® Advanced Vector Extensions 2.0	These extensions increase performance when the same operations are performed on multiple data objects.

Why Intel® Core™ Processors?

Intel Core processors harness significant advancements in CPU performance, security, and power efficiency. These advancements make them ideally suited to power- and space-constrained applications such as IoT gateways.

The use cases tested for this paper compare an Intel® Core™ i7-4700EQ processor with an Intel® Atom™ E3826 processor. Both processors are based on Intel 22nm process technology, have multiple cores, and feature Intel® Virtualization Technology—a feature that can be used with certain operating systems to ensure the real-time deterministic functions important to manufacturing, energy, and other business sectors.

Table 1 lists features that enable an Intel Core i7-4700EQ processor to deliver a significantly higher level of performance than Intel® Atom™ E3826 processors.

Example Use Cases

To demonstrate the performance differences in IoT edge computing between an Intel IoT Gateway-based solution with an Intel Core i7-4700EQ processor and one with an Intel Atom E3826 processor, Intel worked with Allion Engineering, a third-party engineering firm. Using performance metrics such as CPU and memory (RAM) utilization percentages on simulated workloads, the companies compared the performance of the two Intel IoT Gateways and their different processors.

The companies tested the gateways in the following use cases:

- Motion detection
- Face detection
- Search and replace on encrypted workloads

The tests were strictly CPU performance comparisons based on serial code; the processors' integrated graphics processing units (GPUs) were not employed.

Motion Detection Performance Results

Key finding: Intel Core processor-based gateways handle more video streams and thus allow more cameras per gateway and fewer gateways per installation.

If someone is breaking into a building, responding quickly is the highest priority, which is why motion detection is an important analytics capability for digital surveillance systems. When motion is detected, an alarm or alert is activated, and since most networked cameras lack a CPU and can't perform video analytics, their video data must be streamed to a remote server to be analyzed. If the remote server is in a distant building or the cloud, the sheer amount of video data makes this an expensive service. What's more, it can critically slow the process of detection and activation.

Intel IoT Gateway-based solutions provide a better option by enabling motion detection to occur at the edge. Instead of sending feeds to a remote server, the gateway's CPU runs the algorithm that calculates the difference between no activity and motion. This solution enables faster alarm activation, and dramatically reduces bandwidth usage because only the video data needed for evidence gets streamed to the cloud.

In our test, simulated cameras send encoded video streams to the gateways, in resolutions as high as 720p. Each gateway's CPU decodes the streams and runs a motion-detection algorithm on the video stream. The workload outputs an encoded stream of the video frames in which motion was detected.

Motion-detection workloads:

- Video playing at 10 frames per second (fps)
- Light load: 480p content
- Medium load: 720p content

Simulations run by Allion Engineering show the Intel Core processor-based gateway significantly outperforms the Intel Atom processor-based gateway in motion detection in supporting multiple cameras (Figure 5).

In simulation results for the 720p workloads, only the Intel Core processor-based gateway could meet the 10 fps goal for one or more cameras (Figure 6).

These graphs reveal a marked difference in the number of simultaneous light and medium workloads that the Intel Core processor-based gateway can handle compared to the Intel Atom processor-based gateway. Where the Intel Atom processor-based gateway can only handle a single light workload at 10 fps/480p and around 70 percent average CPU utilization, the Intel Core processor-based gateway can run up to five workloads with only 42 percent average CPU utilization. This means that up to 58 percent of processor resources are still available for other tasks.

At 10 fps/720p, the Intel Core processor-based gateway runs up to five workloads with a 76 percent average CPU utilization, reserving up to 24 percent of CPU resources for other tasks.

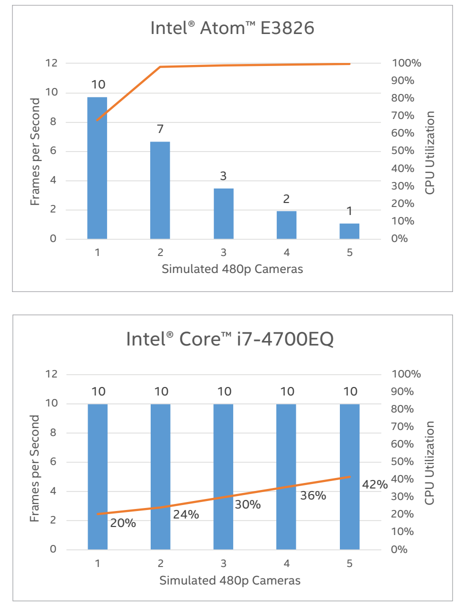


Figure 5. Motion detection performance results for 10 frames per second (fps) at 480p. Orange line indicates average CPU utilization.

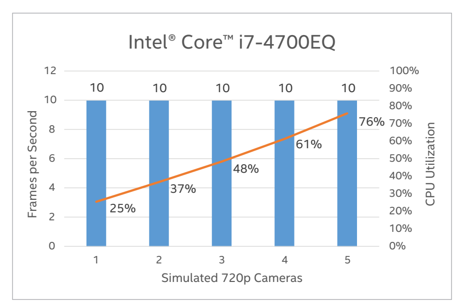


Figure 6. Motion detection performance results for 10 frames per second (fps) at 720p. Orange line indicates average CPU utilization.

Face Detection Performance Results

Key finding: Intel Core processor-based gateways handle more video streams and thus allow more cameras per gateway and fewer gateways per installation.

Facial recognition promises to be a ground-breaking technology in building- access solutions and surveillance. Like our digital video surveillance example, sending video data directly to back-end servers or the cloud to perform the video analytics required for facial recognition taxes bandwidth and increases costs. Using face detection algorithms at the gateway level separates face data from the rest of the video data to dramatically reduce the data needing further analysis.

In our test, simulated cameras send encoded video streams in resolutions as high as 720p to the gateways. Each gateway decodes and runs a face-detection algorithm on the video streams. The workload outputs an encoded stream of the video frames in which faces were detected.

Face-detection workloads:

- Video playing at 10fps
- Light load: 480p content
- Medium load: 720p content

Simulations performed by Allion Engineering compare the performance of the Intel Core processor-based gateway with the Intel Atom processor-based gateway in detecting faces and streaming these video frames to the back-end or cloud.

The results for face detection are similar to those for motion detection. The Intel Core processor-based gateway can handle far more simultaneous workloads than the Intel Atom processor-based gateway with capacity to spare, and only the Intel Core-based gateway was able to perform the 720p test. (Figures 7 and 8)

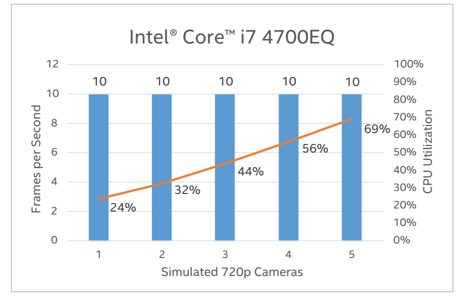


Figure 8. Face detection performance results for 10 frames per second (fps) at 720p. Orange line indicates average CPU utilization.

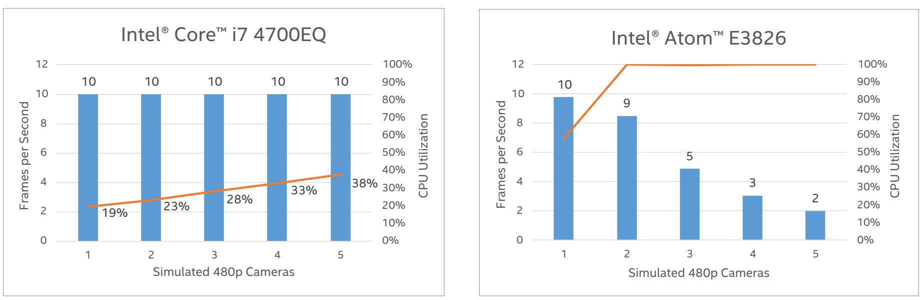


Figure 7. Face detection performance results for 10 frames per second (fps) at 480p. Orange line indicates average CPU utilization.

Search-and-Replace Performance Results

Key finding: Intel Core processor-based gateways handle greater packet processing and filtering workloads, allowing deployment of fewer gateways at the edge to do the same amount of work.

To achieve widespread acceptance, the IoT must ensure the security and quality of service (QoS) of connected things. An important tool for doing this is deep packet inspection (DPI). This form of packet filtering examines the data part (and in many cases the header) of a packet as it passes an inspection point. DPI solutions search for protocol noncompliance, viruses, spam, intrusions, or defined criteria—such as for quality of service (QoS)—to decide whether the packet may pass or if it needs to be routed to a different destination.

A gateway can help reduce back-end or cloud traffic by performing search and replace at the edge, which reduces large stacks of data to smaller pieces. Filtering for data requiring action in the cloud and forwarding only that data to the cloud significantly reduces transmission and cloud computing costs.

In our test, we stream simulated encrypted data packets to the gateways. Each gateway decrypts and searches for particular patterns in the content. The filtering algorithm identifies strings that match these patterns and replaces them with other strings. The content is then re-encrypted and forwarded.

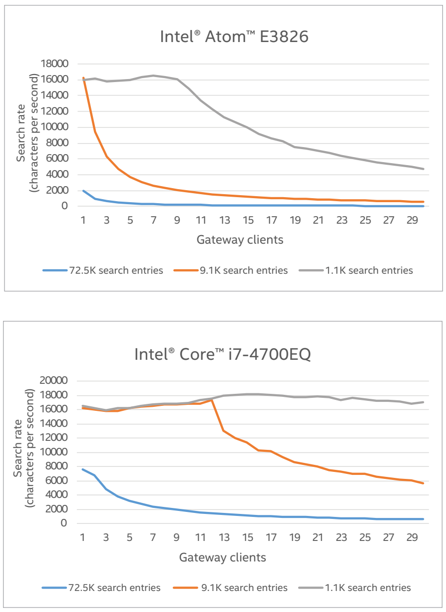


Figure 9. Encrypted search-and-replace performance results.

Search-and-Replace Workloads:

- Light load: 1,138 entries in the key/value replacement dictionary
- Medium load: 9,064 entries in the key/value replacement dictionary
- Heavy load: 72,512 entries in the key/value replacement dictionary

Simulations performed by Allion Engineering compare the performance of the Intel Core processor-based gateway with the Intel Atom processor-based one in this search-and-replace function (Figure 9).

These simulations demonstrate a significant difference in the number of simultaneous light, medium, and heavy workloads that the Intel Core processor-based gateway can handle compared to the Intel Atom processor-based gateway.

System Resource Usage

Resource usage is an important parameter for determining reasonable loads for a platform. Our tests measured resource usage for the CPU and system memory when running light (480p) and medium (720p) workloads for motion and face detection.

As expected, in each case we found that the Intel Core processor-based gateway handled more workloads before reaching maximum utilization due to its greater quantity of system memory and higher compute performance. See Figure 10 and Figure 11 for a comparison of the two processors on medium face-detection and motion-detection workloads.

Figure 10. System resource usage results for face detection, medium load (720p at 10fps). The Intel® Core™ processor can handle streams from up to eight cameras before reaching 100 percent CPU utilization, while the Intel® Atom™ processor reaches its maximum at just two cameras. Memory utilization steadily ramps up with the Intel Atom processor with the addition of more camera feeds, while the Intel Core processor shows a slow increase.

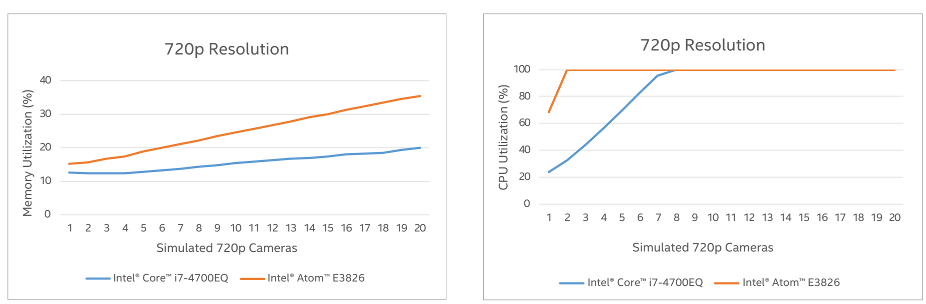
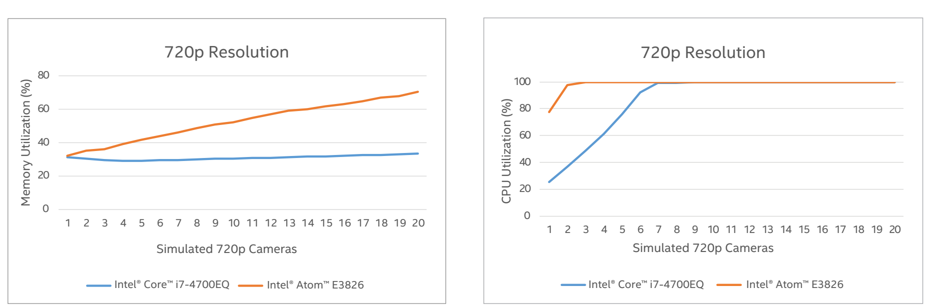


Figure 11. System resource usage results for motion detection, medium load (720p at 10fps). The Intel® Core™ processor can handle streams from nearly seven cameras before reaching 100 percent CPU utilization, while the Intel® Atom™ processor reaches its maximum at just two cameras. Memory utilization steadily ramps up with the Intel Atom processor with the addition of more camera feeds, while the Intel Core processor shows a slow increase.



Conclusion

These test results from Allion Engineering conclusively demonstrate the advantage of Intel Core processor-based IoT gateways for intensive IoT workloads requiring edge processing to do the following:

- Perform more work at the edge
- Reduce network traffic to the back-end or cloud
- Decrease back-end or cloud processing loads and costs

While Intel IoT Gateway solutions based on Intel Atom processors provide excellent performance on data processing and analytics workloads for many gateway applications, Intel Core i7 processors offer a cost-effective solution for handling larger workloads. As companies increase their use of the IoT, such powerful gateway solutions will become an important part of ensuring the optimal performance of edge solutions and use of cloud resources.

Learn more at intel.com/iotgateways.

[1] Source: IMS Research