Intel Smart Factory Solution using 5G and AI Workloads on Network Edge

White Paper

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Revision History

Date	Revision	Description
Nov 2022	0.4	External release.
Aug 2022	0.3	Added three AI use cases with the architecture and description and updated the AI model testing/debug section.
Aug 2022	0.2	Added details of Network and Use Cases Architecture.
Aug 2022	0.1	Initial version.

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1.0 Executive Summary

Manufacturing in the US is on the rise to satisfy the consumer demand and to mitigate the geopolitical risks. Semiconductor manufacturing industry announced 100's of billion dollars to start new greenfield factories. Other industries are investing to retrofit their existing legacy infrastructure using latest technologies. This paper discusses how edge computing, 5G private networks, and Artificial Intelligence (AI) technologies can help businesses in digitally transforming their existing factories as well as building new ones. It proposes end to end solution architecture, discusses recipes for using Multi-Access Edge Computing (MEC), 5G private networks, and AI models powered by Intel platforms and its ecosystem partner products. Intel engineering teams have validated these end-to-end solutions and their readiness for production deployment.

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2.0 Introduction

US led the industrial revolution thru factory automation to improve productivity and increase the output. With globalization, US manufacturing lost its global leadership and its legacy infrastructure need major overhaul. US manufacturing is also faced with two challenges: majority of the workforce retiring and attracting millennials and Gen Z to join the workforce. Digital transformation of US factories has become critical to business survival and to fuel the growth. Businesses are contemplating to build new factories (green field) or modernizing the existing (brown field) factories with latest digital technologies. This paper focuses on how Intel edge compute, 5G, and AI technologies can help businesses in their digital transformation journey.

Greenfield factories can take advantage of 5G private networks to quickly deploy the necessary network infrastructure to monitor construction activities, asset tracking, worker safety, digital surveillance, and other smart campus use cases. Innovative AI solutions from Intel ecosystem partners can be deployed on MEC ensuring interoperability, app isolation, and secure computing. Brown field factories can modernize their existing infrastructure by using AR/VR, computer vision, audio analytics, drone technologies, and sensor technologies to create digital twins for data ingestion and use AI models and 5G private networks running on MEC for further processing.

In this paper, Intel Smart Factory shares some of the AI use cases and services used over private 5G networking and MEC in this reference kit:

- Remote analog gage reading for Fabs using AI recognition
- Condition monitoring of Fab machines using acoustic analysis & AI
- Liquid level monitoring using AI recognition
- Robotic and drones in service
- Badge reader service
- Asset recording and tracking service
- Safety and Smart Security service

2.1 Terminology

Table 1. Terminology

Term	Description
AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
MEC	Multi-access Edge Computing

Term	Description
CPE	Customer Premises Equipment
BBU	Base Band Unit
UPF	User Plane Function
AMF	Access and Mobility Management Function
SMF	Session Management Function
LPR	License Plate Recognition
WD	Weapon Detection
CPRI	Common Public Radio Interface
CBRS	Citizen Broadband Radio Service

2.2 Reference Documents

Table 2. Reference Documents

Document	Document No./Location
Overview of Intel vPro® Platform	https://www.intel.com/content/www/us/en/architecture-and-technology/vpro/overview.html
Intel Smart City Solution Reference Kit	https://cdrdv2.intel.com/v1/dl/getContent/752172

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3.0 Intel Smart Factory Solution Scope and Requirements

Intel Smart Factory Solution is designed to meet the complex FAB environment needs for:

1- Campus Connectivity
Using state of the art methods for different use cases and different end devices, like IP cameras, sensors, drones, robots, AR/VR headsets (such as Hololens), and UEs and laptops, also requirements in terms of availability, stability, throughput, latency, and cost effectiveness.

2- Site Security and Safety
In addition to smart surveillance, the reference kit is using Artificial Intelligence (AI) algorithms to provide safety measures around the campus perimeters, gates, and within the campus zones, tracking mobility, safety codes, and locating individuals when needed.

3- Fab machines monitoring, readings, reporting, and flagging alarms.
AI models and techniques used in this solution to read analog and digital gages, liquid levels, temperatures, gases and emission levels, and acoustic recognition.

For this specific project and to build a BOM and a POC in the lab, we agreed on the following assumptions with the factory experts:

Construction Zone:

- 5 x Construction zones of each 0.25 sq mile
- 100 workers work in each construction zone
- Each construction zone will have a full Wi-Fi 6E tri band (11ax) coverage and sufficient capacity
- Umbrella coverage and capacity of private 5G in every construction zone that support 911 service and all 5G devices and industrial use cases
- Each construction zone has enough 5G CPEs to connect IP cameras, sensors, and other devices needed on 5G system

Parking Lot:

- Average 200 cars in each parking lot
- Parking lots to have coverage of private 5G that support 911 service and all the 5G CPEs in the area
- Parking lots has enough 5G CPEs to connect IP cameras, sensors, and other devices needed on 5G system

Campus Periphery:

- Area of ~ 1 sq mile
- Each side will have four cameras
- Umbrella and backup coverage and capacity of private 5G that support 911 service and all 5G devices and industrial use cases
- Enough 5G CPEs to connect IP cameras, sensors, and other devices needed on 5G system
- 10 IP cameras with
  - Weapon detection AI model
  - License plate recognition AI model
  - Violence Behavior Recognition AI model
  - Construction worker badge reader
  - Asset tracking

5G SA private network:

- Campus to have a private 5G coverage using CBRS carrier to work as an umbrella service
- Nokia NDAC 5G SA system is used for this solution with 1000 users' cap and multiple outdoor radios

More details on the 5G solution in the following sections.

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4.0 Intel Smart Factory Solution Architecture

The Smart Factory Solution is expected to create a smart campus with a fully connected, safer and more secure environment. This solution can be deployed in other Fabs and construction areas.

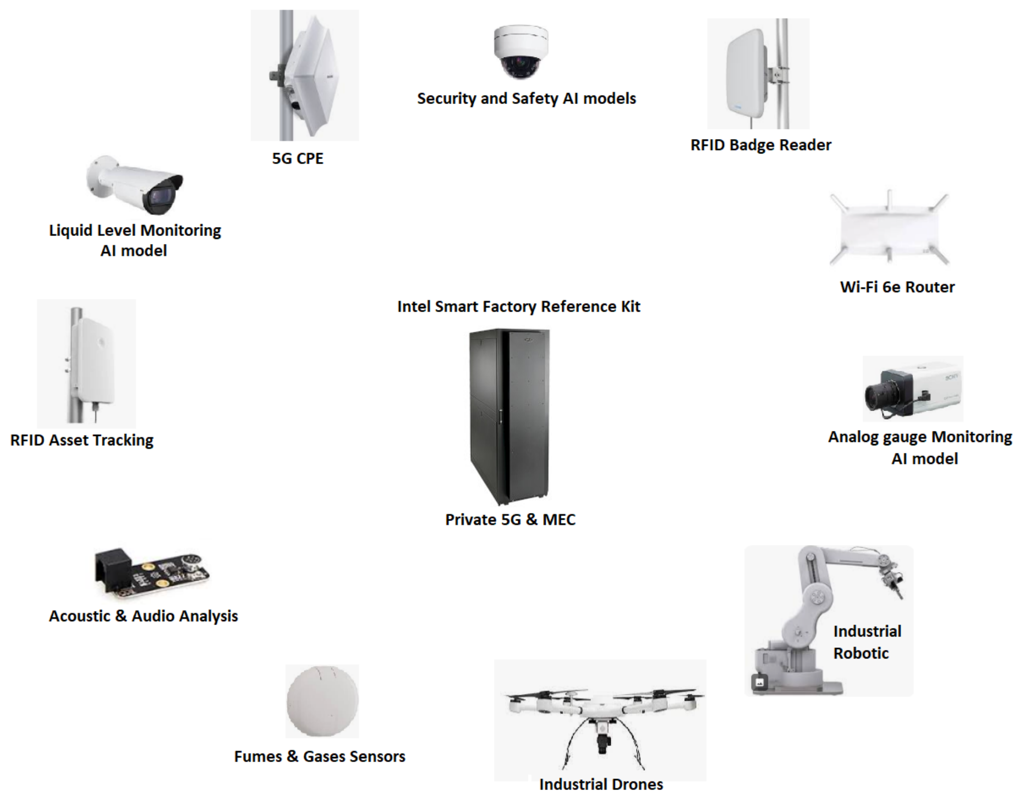

Figure 1 Smart Factory solution architecture

Intel Smart Factory reference kit architecture split in to three major components:

1- The Intel Multi Access Edge Compute (MEC) including:
  a. Physical layer
    i. Intel CPU, this reference kit used two different CPUs, both show great performance and stability
    ii. Intel Accelerator
    iii. Intel NIC cards
  b. Virtual layer
    i. Virtual interfaces
    ii. VMs and VFs

   c. Resource Orchestration
   d. AI models
   e. End to end device management and reporting
      i. Individual component remote management, configuration, alarms, and troubleshooting
      ii. System end to end reporting

2- The Communication and networking part, which includes
   a. private 5G network components
   b. Wi-Fi 6e if required
   c. Bluetooth Low Energy (BLE) if required
   d. IP Networking

3- Customer End points and this include
   a. 5G CPEs,
   b. IP Cameras,
   c. IP sensors
   d. Individual UEs (i.e., laptops and tablets used by factory employees and first responders)
   e. Robotics
   f. Drones

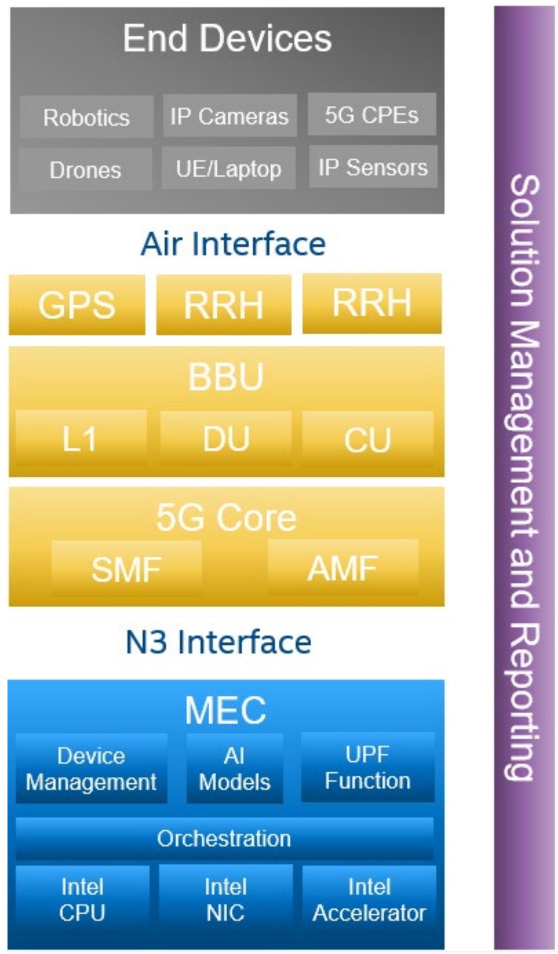

Figure 2 Intel Smart Factory Solution General Architect

Most of the building blocks of this architect, integrated to fit the scalable and variety needs of Smart Factory deployment

The rack will contain the equipment depicted in Figure 3.

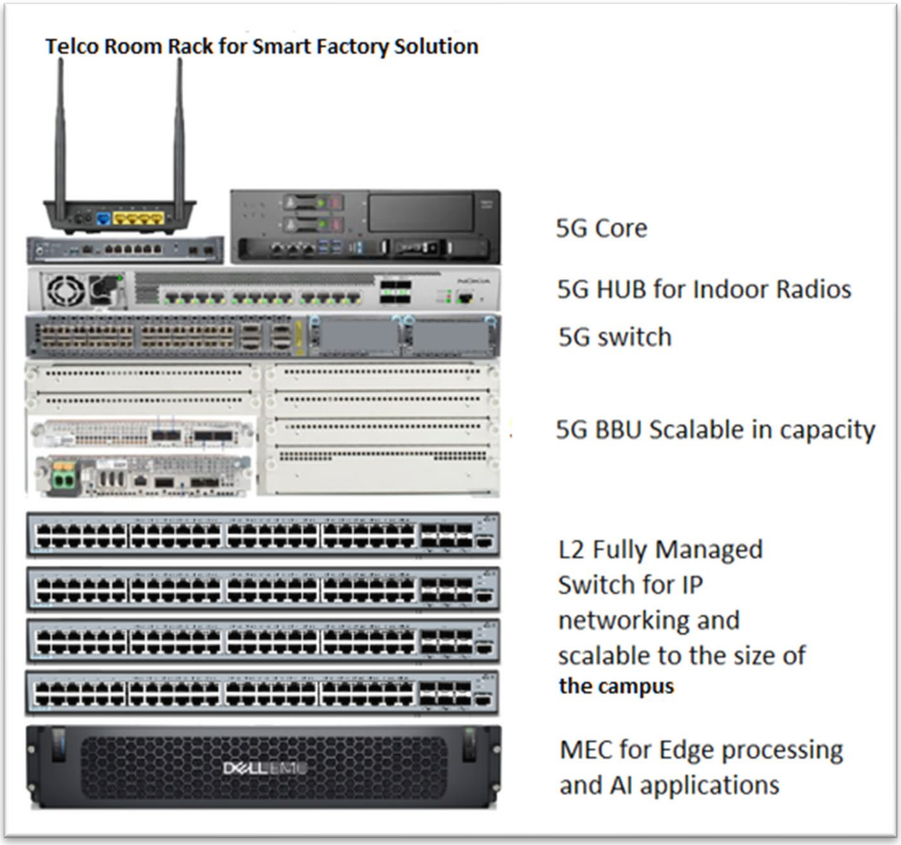

Figure 3 Intel Smart Factory Box

More details about the building blocks of the Intel Smart Factory Solution are below.

4.1 Multi Access Edge Computing (MEC)

Multi-access Edge Computing (MEC) offers application developers and content providers computing capabilities and an IT service environment at the edge of the network. This environment is characterized by the following:

- Proximity
- Ultra-low latency
- High bandwidth
- Virtualization
- Real-time access to radio network information that can be leveraged by applications.

In 5G networking, MEC provides a new ecosystem and value chain. Edge computing developed using open-source hardware and software that leverage cloud and virtualization paradigms, including SDN (Software defined Networking) and NFV (Network Function Virtualization), this make the MEC a natural development in the evolution of mobile base stations and the convergence of IT and telecommunications networking.

Multi-access Edge Computing provides new vertical business segments and services for consumers and enterprise customers with many use cases include:

- Video analytics
- Location services
- Internet-of-Things (IoT)
- Augmented reality
- Optimized local content distribution and
- Data caching

In Intel Smart Factory Solution, the MEC server uses 3rd generation Intel® Xeon® scalable with up to 32 cores and 64 threads, Turbo Freq of 3.4 GHz.

The MEC is built with multiple Intel NIC cards with 10G ports using intel SFP+ to interface with the 5G components, IP cloud, factory networks, and management tools.

Edge Orchestration at Intel Smart Factory MEC is used to manage, automate, and coordinate the flow of resources between multiple types of devices, infrastructure, and network domains. With edge orchestration, network resources are intelligently reallocated and dynamically scaled, reducing resource starvation in applications that need fast response times. By doing so, edge orchestration helps ensure traffic is efficiently routed and that network resources are directed to the correct destination while also ensuring the network can handle any increase in traffic volume or resource.

This MEC is built for challenging environments, including telecommunications, military, and retail. The following diagram shows MEC Stack for Intel solution.

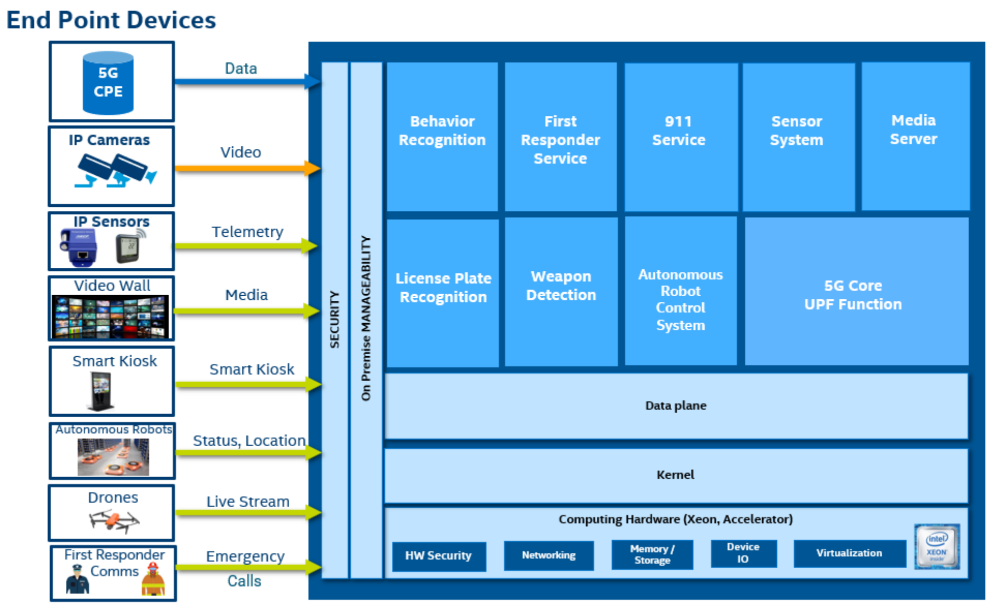

Figure 4 MEC Solution Stack for Intel Smart Factory

4.1.1 AI Models

Different AI models and services added to this MEC based on the customer request to show the system performance and capabilities:

- Badge reader service
- Asset recording and tracking service
- Smart Security and Surveillance
- Smart 911 services
- Remote analog gage reading for Fabs using AI recognition
- Condition monitoring of Fab machines using acoustic analysis & AI
- Liquid level monitoring using AI recognition

Remote Security, Access control, and Assets Tracking

The solution will use (RFID) tags in form of badge for employees and eKeys for cars and mobile machines to:

- Control access to employees and vehicles with different level of privileges
- Track movement of mobile machines, and vehicles in the factory or construction site.
- Track asset movement within the factory

The UHF 433 MHz active RFID antennas can read badges, eKeys, and vehicle tags up to 2000 ft away, other RFID antennas are more focused to smaller areas for asset tracking.

Figure 5 RFID system Antenna for badges and eKeys access control and tracking

On the receiver side many RF tags options with wide range of frequencies can be used to tag mobile machines, vehicles, valuable assets, and so on.

Figure 6 RFID tags

AI model to control and manage the badge and tags tracking and access control is placed in the MEC, the model generates continuous reports to be shared with security, safety, and site management.

Smart Security and surveillance

The solution includes AI models run over IP cameras capture for violence behavior or weapon detection, other models can be added if the customer find the need for them

Violent Behavior Recognition

For details on the Violent behavior recognition visit the reference studies and AI model descriptions below

- face detection
- body gestures
- action recognition.

Weapon Detection

For details on the weapon detection visit the reference studies and AI model descriptions below:

- Handgun_Detection_with_Optimized_YOLOv3.pdf

Other AI models including:

- Remote analog gauge reading for Fabs using AI recognition
- Condition monitoring of Fab machines using acoustic analysis & AI
- Liquid level monitoring using AI recognition

Will be covered in the Factory solution use cases in sec 5

4.1.2 End-to-End Solution Management and Reporting

In the MEC design, a virtual machine created to handle the solution end to end manageability, reporting, and troubleshooting.

The solution will use individual components commercial tools for management and reporting, all credentials to access the components remotely stored in this centralized VM, that has access to the clouds for control and managing and reporting.

The tools used for OTA software updates, software updates permissions and timing are controlled by the MEC device management functionality.

Intel reference kit fallback configuration stored for a successful recovery in case of failure or power outage, system end to end recovery was tested successfully.

Components covered with the centralized end to end device management:

- MEC components, including configuration and AI models
- Private 5G components, including SIM cards management
- 5G CPEs
- IP camera and sensors

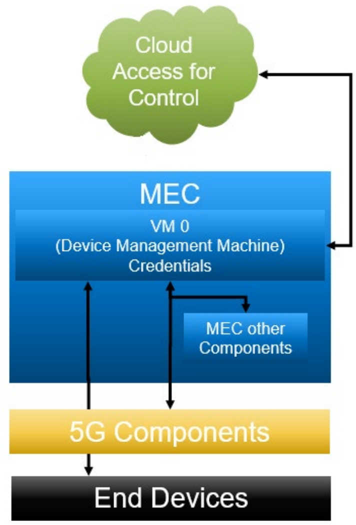

Figure 7 Solution end to end management

4.2 Private 5G Networking

During the design and validation of this kit, Intel examined different choices of 5G private network components, and worked closely with different vendors on select, modify, and configure, the 5G components, to best suite this solution end to end with other components, from performance, capacity, stability, and flexibility aspects.

In this solution we used the Nokia private 5G solution (NDAC) with a 250-user capacity on the CBRS (Citizens Broadband Radio Service) frequency spectrum, and up to eight outdoor remote radios.

Nokia private 5G supports classical gNB architecture. The 5G gNB consists of Air Scale System Module (SM) or BBU (Base Band Unit), this unit includes the following functionalities:

L1 layer, DU (Data Unit) layer, and CU (Central Unit) layer, in addition to the Front Hall (FH) interface management and synchronization using CPRI protocol and GPS

In Intel Smart Factory solution, we used outdoor Remote Radio Heads (RRH), that support the CBRS spectrum in the US, and provide larger TX power and high MIMOs.

4.2.1 5G BBU System Model

The BBU AirScale includes at least one common plugin unit (ASIK) and one or more capacity plug-in units (ABIL) in a sub-rack.

The common plug-in unit provides backhaul Ethernet ports, base station synchronization, central control functions and base station operation and maintenance functions. The capacity plug-in units perform cell-specific baseband processing and include optical CPRI or eCPRI interfaces to radio units.

ABIL
Capacity 5G
ABIL
Capacity 5G
ASIK
Common 5G

Figure 8 Nokia NDAC BBU unit

ASIK common plug-in unit supports 5G NR technology with integrated transport:

- 2x SFP28: for 1/10/25 GE backhaul interface, max throughput 7.5 – 9 Gbps
- Sync IN and OUT, External Alarms and Controls, LMP
- Up to 3 ABIx (e.g., ABIL) units above ASIK
- -48 VDC nominal power, typical power consumption 90 W, max 180 W.

ABIL 5G capacity plug-in unit includes the following features:

- Wideband capacity: 16x 100MHz DL layers
- Narrowband capacity: 4 cell 4T4R @20MHz
- L1 throughput DL/UL: 7 Gbps / 3.5 Gbps
- 2x QSFP28: 8x9.8 Gbps for CPRI fronthaul or 25GE for eCPRI
- 2x SFP28: 2x25 GE for eCPRI or 2x9.8 Gbps for CPRI
- 10 080 RRC connected users
- Typical power consumption 90 W, max 199 W.

The Nokia BBU unit is using Intel Xeon and it hosts the

- L1 layer
- DU (Data Unit) functionality
- CU (Central Unit) functionality

4.2.2 5G Remote Radio Head (RRH)

Intel Smart Factory solution used two different types of RRHs that support CBRS spectrum:

Indoor RRH with 24dBm max on a single TX power, omni field pattern, ethernet interface over e-CPRI protocol, this type of RRHs required Air-Hub device, this RRH is good for indoor deployment or 5G DAS distribution.

Figure 9 Nokia DAC AirScale System model (BBU unit with Remote Radio Heads)

Outdoor RRH with up to 5 Watts per TX path, and up to 4 TX ports, this TX power over directional antennas with beam width of 65 degrees can provide sufficient 5G coverage for long factory streets. this RRH support configuration of 4T4R MIMO for higher throughput.

4.2.3 Deploying Private 5G in a Factory

To achieve a successful deployment of intel smart factory reference kit in any factory, a survey and design are needed to guaranty the solution connectivity for private 5G, in terms of coverage, performance, and capacity, especially when using the CBRS frequency channels and SAS process.

Requirements for saucerful private 5G deployment:

- Availability of CBRS frequency channels, in the area of deployment, 10MHz, 20MHz, or 40 MHz
- The service coverage to exceed -100 dBm Reference Signal Received Power (RSRP) in all the designated areas
- The service Signal to Noise Ratio (SNR) to be maintained at 18dB or better in the serving area
- Provide enough data throughput uplink and downlink to support all use cases and end devices
- Maintain low latency of 10 msecs on 99.99% of all data samples (UE to MEC and vice versa)

4.2.4 5G Core

Standard NDAC system uses HP server HPE EL1000 to run the 5G core functionalities, AMF, SMF, and UPF.

HPE EL1000 has:

- Intel Xeon 16 cores (32 virtual CPUs), 1.7 GHz
- 32 GB RAM
- 2 x 10 GB for integration with customer network

In Intel solution, as explained in the solution architect, we moved the UPF functionality from the 5G core to the MEC for faster connectivity and better traffic control and security.

Moving the UPF to the network edge is also made some of the services easier to deploy like 911 and voice over IP.

4.3 End User Devices for Smart Factory

The Smart Factory Solution offer wide range of end user devices interfaced with private 5G service, or Wi-Fi 6e using the 5G CPE, or using other networking methods like BLE.

Some of the devices are video analytic like IP cameras, and in this solution, we used a 4K IP camera with 60 frames per second, with night vision, and infrared capabilities, but the solution can adapt to any IP cameras used in the customer infrastructure.

The solution runs up to 4 AI models on every camera, processed in parallel using different AI models containerized in the MEC, like License Plate Recognition (LPR), Weapon Detection (WD), Security Surveillance, Violent Behavior Detection, Analog gauge reading, Assets tracking, and so on.

Different IP sensors introduced in the solution, connected with different interfaces, Wi-Fi, BLE, Ethernet, or using a sensor hub.

UEs, laptops, and tablets, for data browsing, also used by factory employees, and first responders, usually QoS of these devices set to lower class at best effort to avoid any throttling on the air interface or resources. Devices should have 5G modem that support CBRS frequency.

Robots, and Drones, are used if recommended by the customer, both tested in different POCs on the same configuration successfully.

Finally, the 5G CPEs, in this reference kit used to connect IP components that do not have 5G modem yet.

The outdoor 5G CPEs used in this solution support the CBRS frequency and are remotely managed. The max TX power is 1 watt for better reception and coverage.

The CPE has ethernet ports to connect nearby IP cameras and sensors using ethernet connections and has Wi-Fi triband router that can support up to 30 devices at the same time.

Figure 10 Outdoor IP cameras served by 5G CPE

5G CPE can configure the routes, the IP subnets, the security level, and manage the nodes to connect.

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5.0 Factory Solution Use Cases

Industrial use cases are intended for Intel Ocotillo Fab.

5.1.1 Liquid Level Monitoring

The water processing plant in Intel Fab makes use of many different types of liquid chemicals to treat the water. These chemicals are stored in small bottles (gallon size) or in huge tanks. The chemical level in these bottles and tanks are monitored either by manual inspection (example on the left in below image) or by using plunger like analog gauge as shown in righthand side of image below.

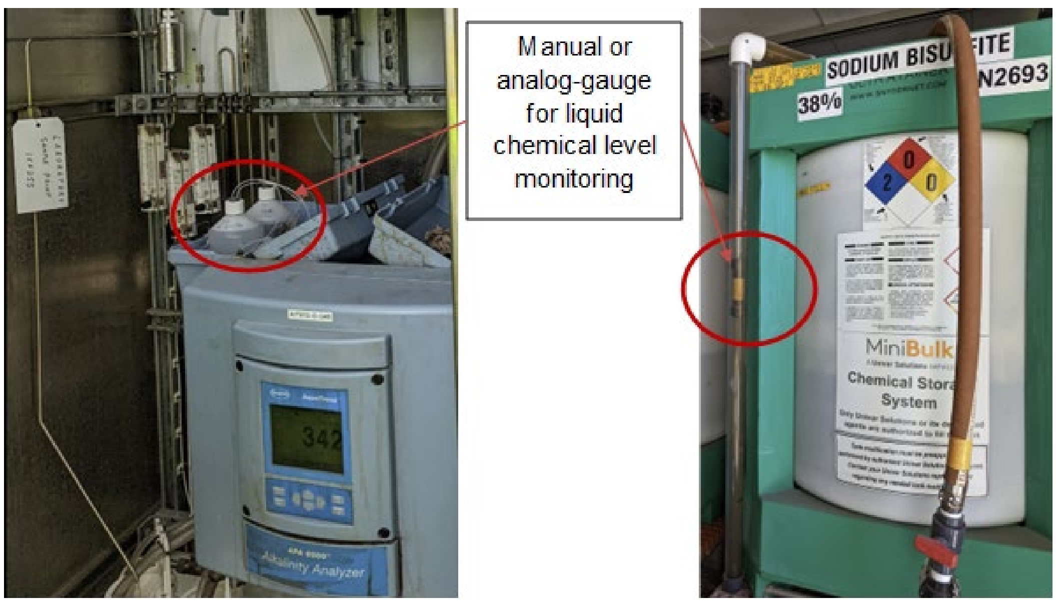

Figure 11 Manual or Analog gauge for liquid chemicals level monitoring

Types of Sensor Technology

There are six different methods or sensors technologies to measure liquid level in the container. These methods are different design approaches. The following sections describe these six methods.

Continuous Float Level Transmitters

These level monitors operate by using a float suspended in or on the fluid from a rod, something of a dipstick, which sends a vibration up the rod to a sensor. There are two main types. In Magnetostrictive designs, the float carries a magnet which disrupts the electrical pulse sent down the rod from the sensor. The return vibration (strain pulse) is timed, and the level of the float determined. Resistive Level Sensors utilize the same rod and magnetic float set-up; however, now, the rod contains reed switches with resistors. As the float rises and falls, these switches close and change the resistance of the circuit. The resistance indicates the float position to the sensor. A second set of floats and sensors can be installed to measure levels of two different fluids. For example, if you wanted to check an underground storage tank for water leakage, two sensors could be used to determine if one fluid (oil) was floating on a second fluid (water).

These measurements are accurate. One advantage to the float measurement is accuracy in foamy media. Non-contact technologies, like ultrasound, may give false readings under these conditions.

Requiring contact, however, leads to disadvantages. You may not desire contacting the medium. The materials in your rod or floats may not be compatible with the medium. Temperature and buoyancy issues may alter the accuracy of the results. Finally, the displacement of the floats and rods in much smaller vessels may drive imprecise results. Continuous float level transmitters are appropriate and accurate for typical applications.

5.1.2 Acoustic Monitoring

There are large number of machines that continuously run in the water treatment plant and each machine makes certain type of noise when they are operating well. The noise level and type changes when these machines are faulty or need maintenance. A technician walks around every day to listen to the noise in the plant room to make sure the noises are normal. If they hear any abnormalities in the noise, they will look for the making abnormal noise and then try to identify the issue. An acoustic monitoring system enables continuous monitoring of many machines and equipment simultaneously with only few simple sensors. Use of machine learning at the edge enables detection of anomalies and clustering of typical machine behaviors and issues.

The acoustic monitoring system enhances safety and security of water treatment plant and can report an issue or future issue in advance. It also helps to eliminate dependency on a technician who is experienced in listening the noise to identify any issues.

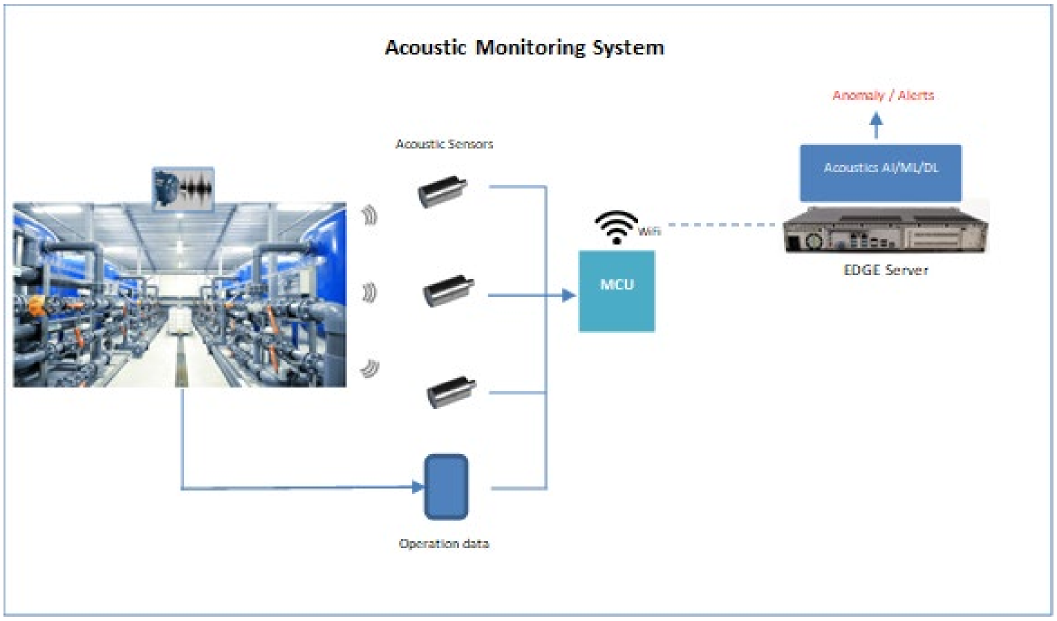

Figure 12 Acoustic Monitoring system using microphone

Above figure shows an example of an acoustic monitoring system. It is comprised of several acoustic sensors placed in the processing plant or the room. The MCU continuously samples and transmits the sound or the noise from the processing plant to the EDGE server. The EDGE server runs acoustics AI application which then detects any anomaly and sends out alerts for further investigation.

5.1.3 Analog Gauge Reading Using Camera and AI/ML

There are hundreds of analog gauges used in industrial factories like Intel's Fabs and Sub Fabs that includes pressure, temperature, humidity, voltage, current, and so on. These analog gauges are read by a technician several times a day and most of the readings stay in the technician's notepad. In the case of any anomaly or out of threshold reading the technician would act or escalate to the next level. It would require a huge infrastructure upgrade to replace analog gauges with equivalent digital and smart gauges that can transmit the telemetry data. The following image shows an overview of how AI/ML can be used to read analog gauges in real time.

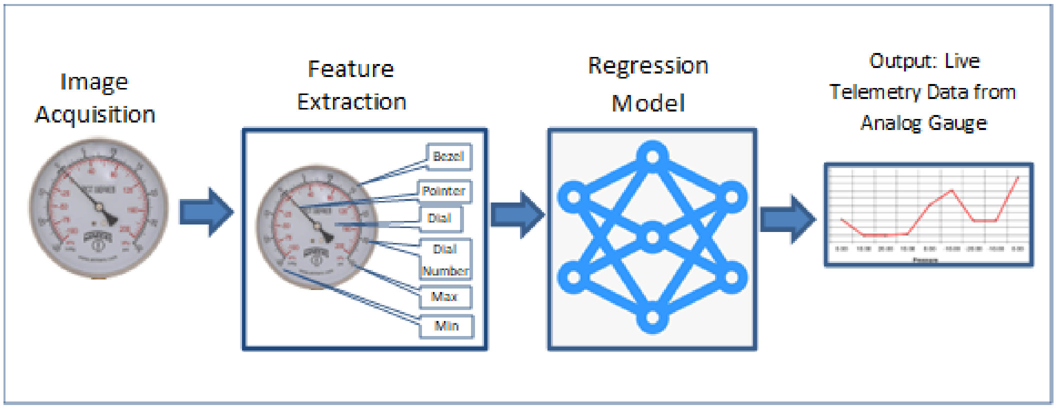

Figure 13 Analog gauge using AI

There are two approaches we are considering in this document to acquire an image at certain time interval.

5.1.3.1 Using a Fixed Camera

A camera is fixed to the analog gauge as shown in figure below. The camera is connected to an edge server using either Wi-Fi or wired ethernet. This approach is safe because there are no moving parts. Once the cameras are installed, the image acquisition can be set to real time or at a specific time interval. However, number of cameras can increase the one-time.

Figure 14 Image acquisition using a fixed camera

5.1.3.2 Using a Drone:

Figure 15 Image acquisition using a drone

A drone equipped with camera can go around the plant and take pictures of analog gauges and transmit them to the edge server over Wi-Fi. This approach does not provide live streaming of analog gauges, but the drone can be programmed to fly and read analog gauges at certain time intervals. The only downside of using drones is safety concerns, the possibility of collision with any moving parts or an untrained human. The drone relies on a GPS signal to fly to a specific coordinate, so a good GPS signal is required inside the plant, or a GPS receiver needs to be installed inside the plant where drone is expected to fly and read analog gauges.

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6.0 Solution Testability and Debug

In this section we share some of the methods we used to test and validate the system end to end functionality, performance, and stability.

6.1 Private 5G Components Testing Using Protocol Analyzers

UE-based protocol analyzers require the use of a 5G UE to connect to a 5G network; the analyzer obtains all metrics and statistics of the 5G connections via the 5G UE.

The analyzer creates a log of all records and signaling between the UE different protocol stack and 5G system stack, data can be used in reporting and debugging.

6.2 Private 5G Components Testing Using Vendor GUI Test Bed

Vendors have their own performance and testing tools that can help identify the major KPIs (Key Performance Indicators) at distinct levels:

6.2.1 Radio Level

At this level, the radio generates a trace log of all communications with the FH front hall including encrypted data, and how many UEs are actively scheduled, and the size of the transport block size.

6.2.2 L1 and MAC Layer Information and KPIs

At this level, the operator can get the synchronization reports and timing for scheduled blocks, as well as a report of missing blocks and out-of-sync blocks.

The operator can also get a report of L1 communication with L2 layer, how many UEs in scheduler, blocks in queue, and other information if more details are required, call trace or layer level trace can be set to collect all messages on L1 layer.

6.2.3 L2/L3 Layers Communication

In this layer, RLC, PDCP, and bearer communications can be monitored and traced. Data at this level is encrypted, but just monitoring the data flow from CU to DU to L1 will give a good indication of L2/L3 layers performance and data flow without discarding or losing any of the frames.

6.2.4 5G Signaling E2E

In this level of communication all signaling flow is traced for:

- RRC (Radio Resource Control) layer
- NAS (Non-Access Stratum) Layer

Example of this signaling is

- UE attach signaling steps including any rejection of failures
- UE paging
- UE release

6.2.5 Major KPIs of 5G E2E Evaluation

This are some of key indicators used to monitor the 5G components performance as follows:

1- Attach success rate
2- Paging success rate
3- HO success rate if applicable
4- Dop calls rate
5- Release success rate
6- DL data throughput per user
7- DL Data throughput aggregated per radio
8- UL data throughput per user
9- UL data throughput aggregated per radio
10- Data latency
11- Packet loss rate
12- Signal to noise ration
13- RSSI and RSRP per user
14- RSRQ per user

6.2.6 AI Model Testing and Debugging

The inference results of the AI use cases are usually appended to the input video frame or saved in a text file to test the core functions. The output video containing the inference results could also be streamed over to the display unit to notify the customers on demand. The pre-trained models are optimized with different precisions using the Model Optimizer command-line utility in the Intel OpenVINO toolkit to identify the model that satisfies the computational complexity of the device under test, while achieving the required accuracy. The performance benchmarking involves evaluating the model with DL Benchmark across different precisions using the metrics such as CPU utilization, memory usage, and inference throughput. This helps to assess the number of independent model instances that could be executed on the edge device under test.

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7.0 Results

7.1 System Stability

The reference kit passed all the system stability and stress test requirements for commercial deployment, including individual stand-alone components and collective system. Below are some of the key indicators for system end to end stability.

Table 3. System Stability Indicators

Category	E2E System
End to End System Stability based on 1000 hours	>99.999%
System automatic recovery in case of complete system outage (all servers, switches, and radios)	less than 300 seconds
UEs Connectivity for 250 UEs after system recovery in first 10 minutes	100%
Number of registered SIM cards in 5GCore	250
Number of concurrent active radio bearers	250
Number of active users on a scheduler	250
Number of QOS classes	7
AI models in first 10 minutes (3 models on each camera, 3 cameras, total 9 AI models)	9 or (100%)
max number of core utilization in VM1 (4 cores)	2
max number of core utilization in VM2 (24 cores)	19
VM1 packet loss rate on physical interfaces	0.001%
VM2 packet loss rate on physical interfaces	0.001%

7.2 System Functionality & Performance

Individual functionalities of all components of the system were evaluated successfully.

- Networking components including private 5G
- Network Edge
- AI and ML models
- IP cameras and Sensors
- Safety and security features
- O&M and device management

7.2.1 Best Effort end to end Throughput Performance

End to end Downlink Data Throughput on a 40MHz channel, aggregated was 200Mbps at RSRP >-100dBm, DL throughput capped at 10Mbps per UE per application.

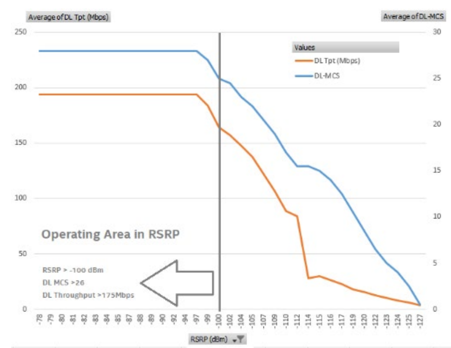

Figure 16 DL Performance in MCS & Throughput vs. RSRP

Uplink Data Throughput on a 40MHz channel, aggregated was 50Mbps at RSRP >-100dBm, UL throughput capped at 5Mbps per UE per application.

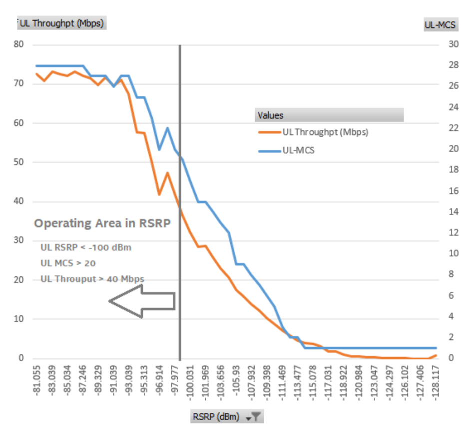

Figure 17 UL Performance in MCS & Throughput vs. RSRP

Data throughput analysis suggest best operating area is when RSRP > -100 dBm, network coverage designed to satisfy this condition.

7.2.2 End to End Latency Performance

The latency test using 64bytes packet ping, the end-to-end results show all samples met the 10 msec criteria of 5G latency, at jitter less than 2 msec.

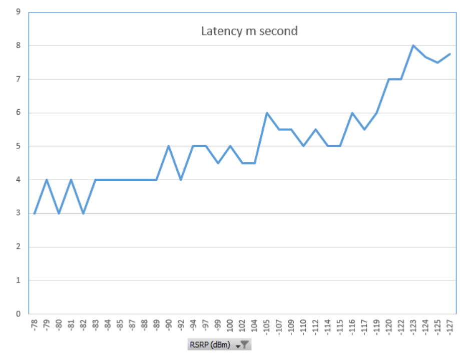

Figure 18 Latency (round trip time) from UE to MEC and vice versa

7.2.3 AI Model Performance in Detecting the Event

AI model stability in analyzing data per frame and reporting the result in time meets the performance and stability requirements on all AI use cases.

In visual AI models, number of reported frames per second, picture resolution, and processing scheduling, can be tuned per use case to maximize the system efficiency and best utilize MEC resources and data throughput requirements.

For example: Analog gauge reading, or liquid level monitoring use cases, a single frame per second at 2K resolution can be sufficient to get good tracking of the readings without the need of high processing power or pipe size. In other hand, use cases like weapon detection, or license plate recognition use cases, 60 frames per second at 4k resolution is needed for best results.

The goal of tuning the use case configuration it to maintain 100% accuracy in detecting the event while stay efficient is resource utilization.

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8.0 Conclusion

Intel Smart Factory solution reference kit was architected and engineered based on recommendations by Fab architects, employees, safety, and security experts. The reference kit is designed to depend on Intel products and solutions.

The solution results and evaluation prove the readiness of the reference kit for commercial deployment.

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