Intel Smart City Solutions with Private 5G and Network Edge

White Paper

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Revision History

Date	Authors	Revision	Description
November 2022	- Lakshmi Talluru (AI Software Engineering Manager) - Majdi Abdulqader (AI Solution Architect) - Ramesh Perumal (Computer Vision Engineer) - Pranav K Sanghadia (AI Solution Architect) - Sindhu Pandian (Software Enabling and Optimization Engineer)	1.0	Initial release.

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1.0 Executive summary

Cities across the world spend majority of their budgets to deal with traffic congestion, emergency response, and public safety of their citizens. This paper discusses an innovative smart city solution that not only supports a city's needs, but also provides new revenue opportunities through digital services for their citizens.

Intel has architected an end-to-end network edge-based smart city solution that uses the latest Intel technologies, best in class artificial intelligence (AI) models, and private 5G networks from industry leaders. This solution provides the necessary compute and network edge platform to support an expanded portfolio of digital services from various solution providers. It can be centrally managed to optimize the Total Cost of Ownership (TCO). This solution is validated in Intel labs and provides the best system stability, functionality and performance, and better TCO.

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2.0 *Introduction*

Cities across the world spend majority of their budgets to deal with traffic congestion, emergency response, and the public safety of their citizens. Cities can benefit from the latest advances from Intel technologies, Artificial Intelligence (AI) models, and private 5G networks. These technologies offer cities with smart solutions to not only deal with their current challenges, but also offer new revenue opportunities such as curb side management, new revenue opportunities for local businesses, and enhanced public safety. Cities prefer a smart network edge platform that is extensible, scalable, and stable, can provide digital services from select vendors. The platform should also be manageable and cost effective and blends well with city's cultural norms. The network edge platform and end points should be secured and protected from vandalism or theft. It should be open standards based to prevent vendor lock-ins.

With these city needs in mind, Intel architected a comprehensive network edge solution using private 5G network, multi access edge computing that can process various AI models, and digital services to better support city's needs. This paper describes a commercial deployment ready solution that is scalable to cover major city. It incorporates 5G private network edge with best-in-class AI models to detect and predict violence, manage traffic flow, and avoid throttling in narrow historic streets. This solution is built in Intel labs is fully validated for functionality, performance, reliability, manageability, and stability. This paper discusses the network edge solution architecture, key building blocks such 5G network, Multi-Access Edge Computing (MEC), and 3 use cases using AI models. The solution architecture is extensible to other digital services / workloads from third-party vendors to meet specific city's needs

The target audience are system integrators (SI), software vendors, city's IT providers, and network edge ecosystem partners

2.1 Terminology

Table 1 Terminology

Term	Description
AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
MEC	Multi-Access Edge Computing
CPE	Customer Premises Equipment
BBU	Base Band Unit

Term	Description
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
Private 5G FCC regulations	https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview
Overview of Intel vPro® Platform	https://www.intel.com/content/www/us/en/architecture-and-technology/vpro/overview.html

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3.0 Intel Smart City Solution Scope & Requirements

The scope and the wish list of this solution was discussed and debated with city officials, security experts, first responders, city vendors, and partners.

The solution to improve:

- Street's connectivity, with reliable and secure high data throughput for first responders, city employees, and city applications, including future use cases like robotics and drones, which needs low latency and very high-performance network edge.
- Street's safety, using best in class AI models to detect and alert any possible criminal violation including:
  - Weapons detection
  - Violent behavior detection
  - Smart Surveillance
  - Smart 911 service
- Traffic flow and management, including parking and traffic violation using AI models like
  - License Plate recognition

The Intel Smart City solution reference kit was engineered to fit and blend within the city infrastructure, aesthetics, and make the solution as compact as possible without sacrificing the scope and functionality of the solution.

The solution is designed to be completely wireless, and all components including outdoor radios, 5G CPEs, IP cameras, sensors, and so on. to be mounted on city infrastructure like lamp posts, and the reference kit in compact outdoor box that can be secured in small footprint.

Figure 1 Intel Smart City Kit on City Light Poles

The solution is scalable and has the flexibility to add different use cases, sensors, IP cameras, and security features that the city may decide to add in future.

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4.0 Smart City Solution Architecture

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

1- The **Intel Multi-Access Edge Compute (MEC),** which includes
   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

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

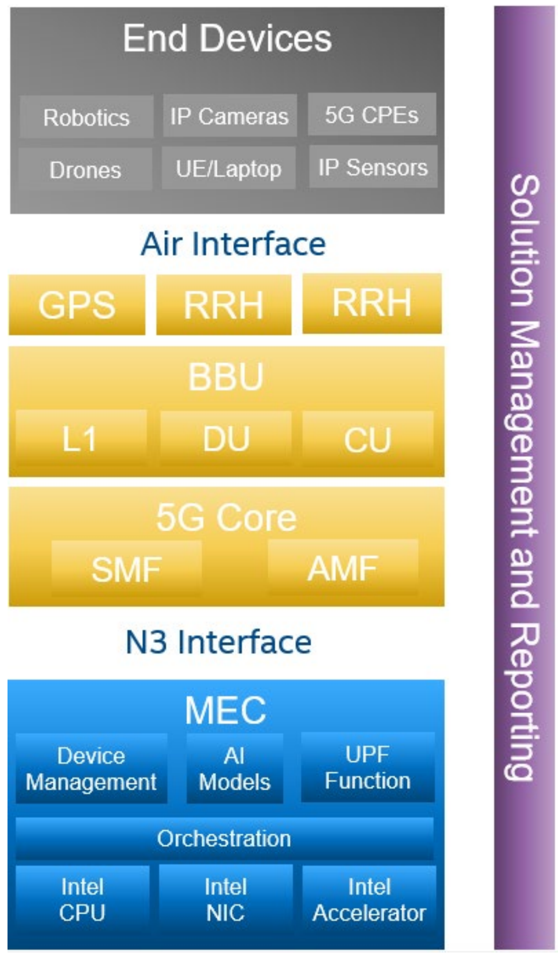

Figure 2 Intel Smart City Solution General Architect

Most of the building blocks of this architect, can be integrated to fit the Smart City deployment and scaling in outdoor rack with AC units and capacity of 14U mounted and secured either next to the light pole or underground

The rack contains the equipment depicted in Figure 2.

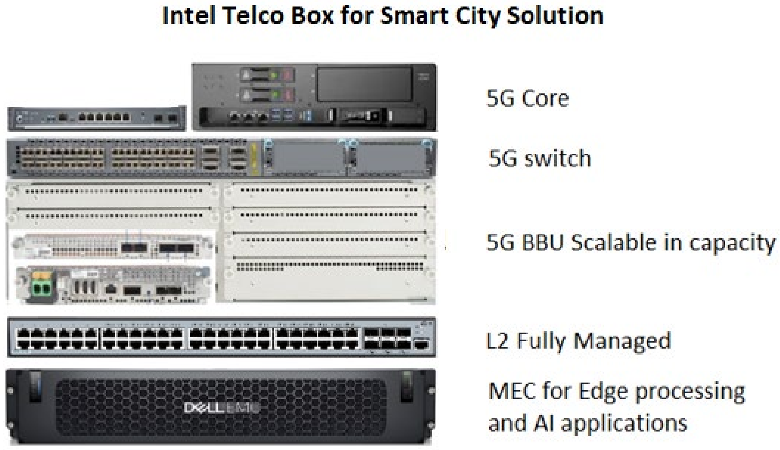

Figure 3 Intel Smart City Box

More details about the building blocks of the Intel Smart City 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 Software defined Networking (SDN) and Network Function Virtualization (NFV), 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 City Solution, the MEC server uses 3rd generation Intel® Xeon® Scalable with up to 32 cores and 64 threads, Turbo frequency 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, city networks, and management tools.

Edge Orchestration at Intel Smart City 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.

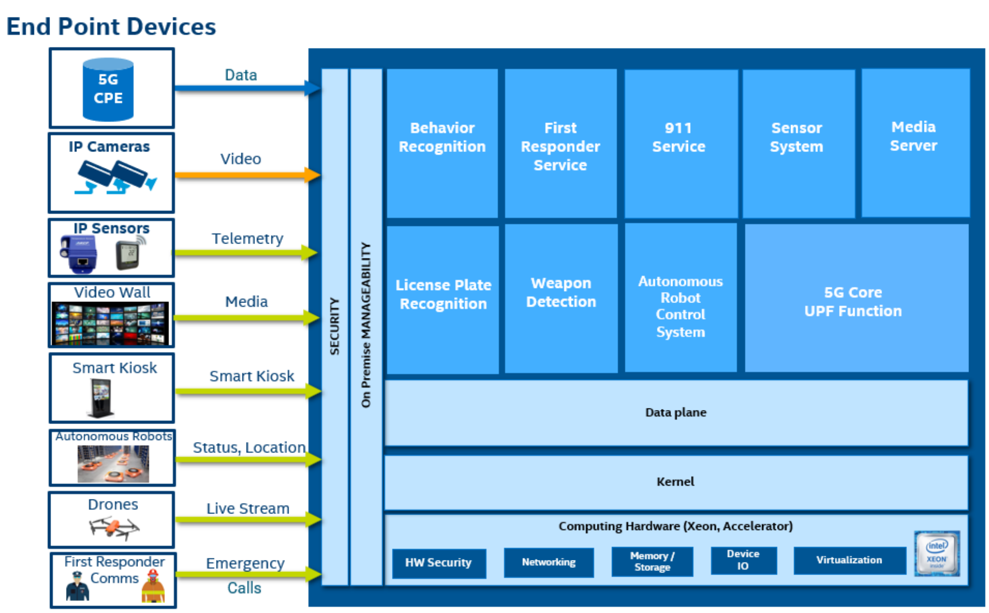

Figure 4 MEC Solution Stack for Intel Smart City

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:

- Smart 911 services
- Smart Security and Surveillance

- License plate recognition
- Weapon detection
- Violent behavior recognition

License Plate Recognition (LPR)

License Plate Recognition (LPR) plays a vital role in the security barrier and smart parking use cases to identify the vehicles. The architecture of deep learning-based ALPR in Figure 9 involves the following two stages: vehicle and license plate (LP) detection and optical character recognition (OCR). In this solution, the pre-trained model based on MobileNetV2, and SSD is used to detect the vehicles and license plates captured at frontal views. While the OCR module includes the image processing operations to transform the LP image into an enhanced binary image to reliably decode the LP number with PyTesseract. The pre-trained model is optimized with Intel OpenVINO™ toolkit to achieve optimal performance on Intel platforms. Furthermore, the GStreamer Video Analytics pipeline is used to implement the ALPR pipeline. This ALPR solution is computationally efficient and suitable for real-time implementation in resource-constrained edge devices (Intel VPU-based smart cameras, for example). Its major limitation is that it can detect the LP only if the vehicle stops within the predefined bounding box in front of the camera.

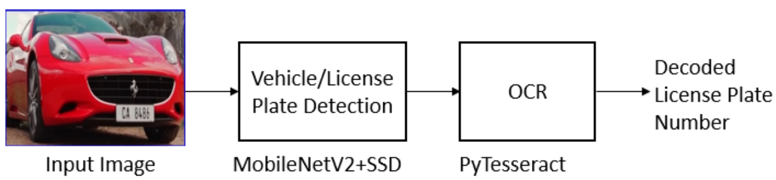

Figure 5 Architecture of Automatic License Plate Recognition

Unconstrained Automatic License Plate Recognition

Most of the existing LPR methods are limited to detecting the vehicle LPs captured at frontal views. Due to this, the detection performance degrades with the distorted LPs in unconstrained scenarios where the vehicles are captured at non-frontal views due to oblique shooting angles. As shown in Figure 10, the vehicle detection (with YOLOv2, for example) facilitates the detection of multiple vehicles in the input image. The resulting detection outputs are resized based on the vehicle bounding box and then fed to the LP detection based on Warped Planar Object Detection Network (WPOD-NET) model. The major contributions of WPOD-NET are summarized as follows: (1) to detect the distorted LP at non-frontal views; (2) to estimate the distortion to unwarp the LP into a horizontally- and vertically aligned object. The WPOD-NET model is optimized with Intel OpenVINO™ toolkit to achieve optimal performance on Intel platforms. The unconstrained ALPR solution is applicable to traffic violation detection and automated access validation use cases as it could detect the distorted LPs in the vehicles.

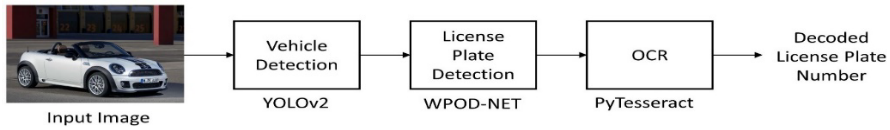

Figure 6 Architecture of unconstrained automatic license plate recognition

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

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 uses 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 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

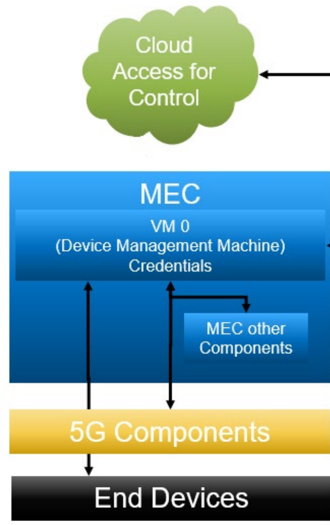

Figure 7 Solution End-to-End Management

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 Citizens Broadband Radio Service (CBRS) 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 City 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.

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 City solution uses 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 city streets. this RRH support configuration of 4T4R MIMO for higher throughput.

4.2.3 Deploying Private 5G in a City Street

To achieve a successful deployment of intel smart city reference kit in any city street, 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 City

The Smart City 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, or Violent Behavior Detection.

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 city 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, can be used if recommended by the customer, both tested in different POCs on the same configuration successfully.

Finally, the 5G CPEs, in this reference kit the 5G CPE 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 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.

5.1 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

5.2 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:

5.2.1 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

5.2.2 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.

5.2.3 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.

5.2.4 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

5.2.5 Major KPIs of 5G E2E Evaluation

This is some of key indicators used to monitor the 5G components performance:

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

5.2.6 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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6.0 Results

6.1 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%

6.2 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

6.2.1 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

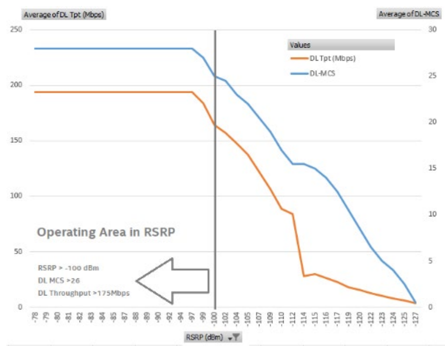

Figure 11 DL Performance in MCS & Throughput vs. RSRP

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

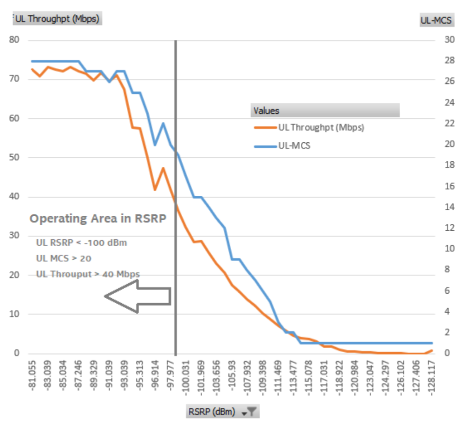

Figure 12 UL Performance in MCS & Throughput vs. RSRP

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

6.2.2 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.

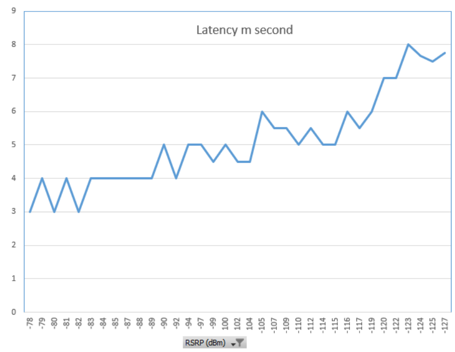

Figure 13 Latency (round trip time) from UE to MEC and Vice Versa

6.2.3 AI Model Performance in Detecting the Event

AI model stability in analyzing data per frame and reporting the result in time is very good and stable, below is a sample data from weapon detection AI model on 4K camera with 60 frames per second, running on Intel Smart City MEC, reporting the event of weapon detection in this repeated video 1,441,316 times, which is equal to the number of the video auto reply.

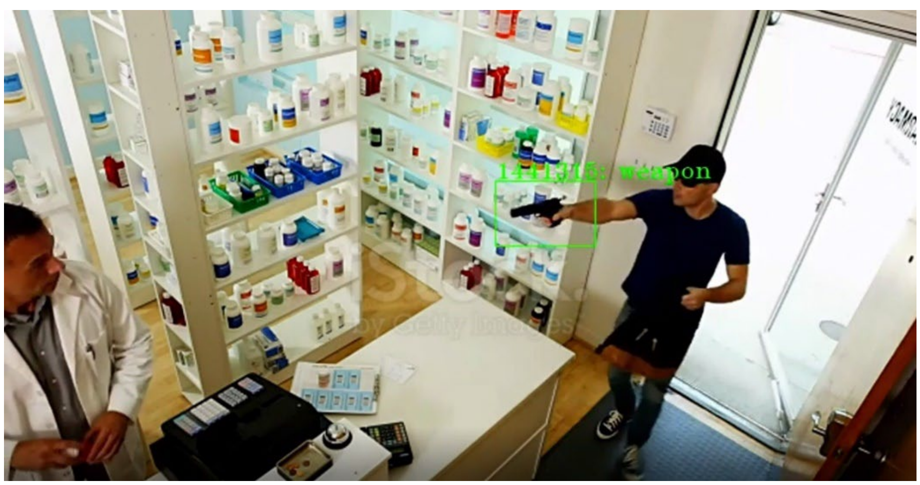

Figure 14 Weapon Detection on One of the Cameras Using AI Model

7.0 Conclusion

Intel Smart City solution reference kit was architected and engineered based on recommendations by city officials, 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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