UWC Software from Intel

User Guide for UWC

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1.0 Introduction

The Intel® UWC is a reference design for a secured management platform that gives third party application developers an easy access to data services including data collection from field devices, control data pathways, and connections to centralized data systems (i.e. SCADA) for Upstream Oil and Gas facilities including gas well sites.

The Intel UWC platform will provide a secure, management platform for oil and gas upstream process monitoring and control to support oil and gas installations with various artificial lift methods such as plunger lift, gas lift, gas-assisted plunger lift, rod-beam and electronic submersible pump (ESP).

Intel's primary objective in this market is to move the Upstream Oil and Gas vendors, service providers, and end-users to adopt Intel-based hardware hosting a rich range of open-architecture software-defined platforms. Solution is targeted to address multiple pain areas O&G industry is facing in day-to-day operations. These pain areas are further restricting O&G industry to get benefitted from technology advancements resulting from cloud-based services and applications for business intelligence (BI), analytics, dashboards, etc. There is a need to provide a uniform mechanism to connect, monitor and control various devices in an O&G well-site adhering to real-time nature of the industry.

While the Intel UWC software solution described in this Users' Guide contains a data model specific to a Gas Wellpad, the software is flexible and can be configured for use with other soft-RT process control sites and operating assets.

1.1 Purpose

This document provides information on how to install UWC software framework and configure the device models, data model and data flows for data collection (from field devices) and reporting (such as to SCADA) at remote process control sites such as a natural gas well Oil (Wellpad). The document will help the developer to evaluate the performance of the data collection processes using an applet called the 'KPI Application'. The document will; help the developer to set up the security and manageability services.

1.2 Scope

This document aims to provide steps to build, deploy and check how gateway up and running all containers. This document also provides steps to set UWC containers for communication with Modbus devices.

1.3 System Requirements

- Intel processor family
- 4GB memory
- 25GB hard disk space
- Ubuntu 18.04 server operating system with RT Patch (instructions for patching the Ubuntu OS are provided)
- Docker >=19.03.8
- docker-compose version >=1.24.0

2.0 Before Installation

This section explains various concepts used throughout this document.

2.1 UWC for O&G site

The UWC is a reference design that provides a secure, management platform for oil and gas upstream process monitoring and control to support oil and gas installations with various artificial lift methods such as plunger lift, gas lift. UWC is a profile on Intel Edge Insights (**EII**) base platform.

UWC provides.

- Soft-real time deterministic control (millisecond level control) in the containerized environment
- Configurable user-defined data model describing Oil well site.
- Modularized microservices-based extensible open architecture.
- Well defined message flow and payload to interact with the vendor application.
- Policy-based execution of Soft-RT applications
- Supports multiple well pads and devices configurations.
- Polls and controls multiple devices simultaneously
- Data Publish Subscribe ZeroMQ and MQTT
- Device Management – System Telemetry, over-the-network (aka over-the-air, or OTA) updates of firmware (FOTA), system software (SOTA), and applications (AOTA)
- Scalable-down to power-sensitive remote applications
- Scalable-up to edge analytics and vision through the EII base

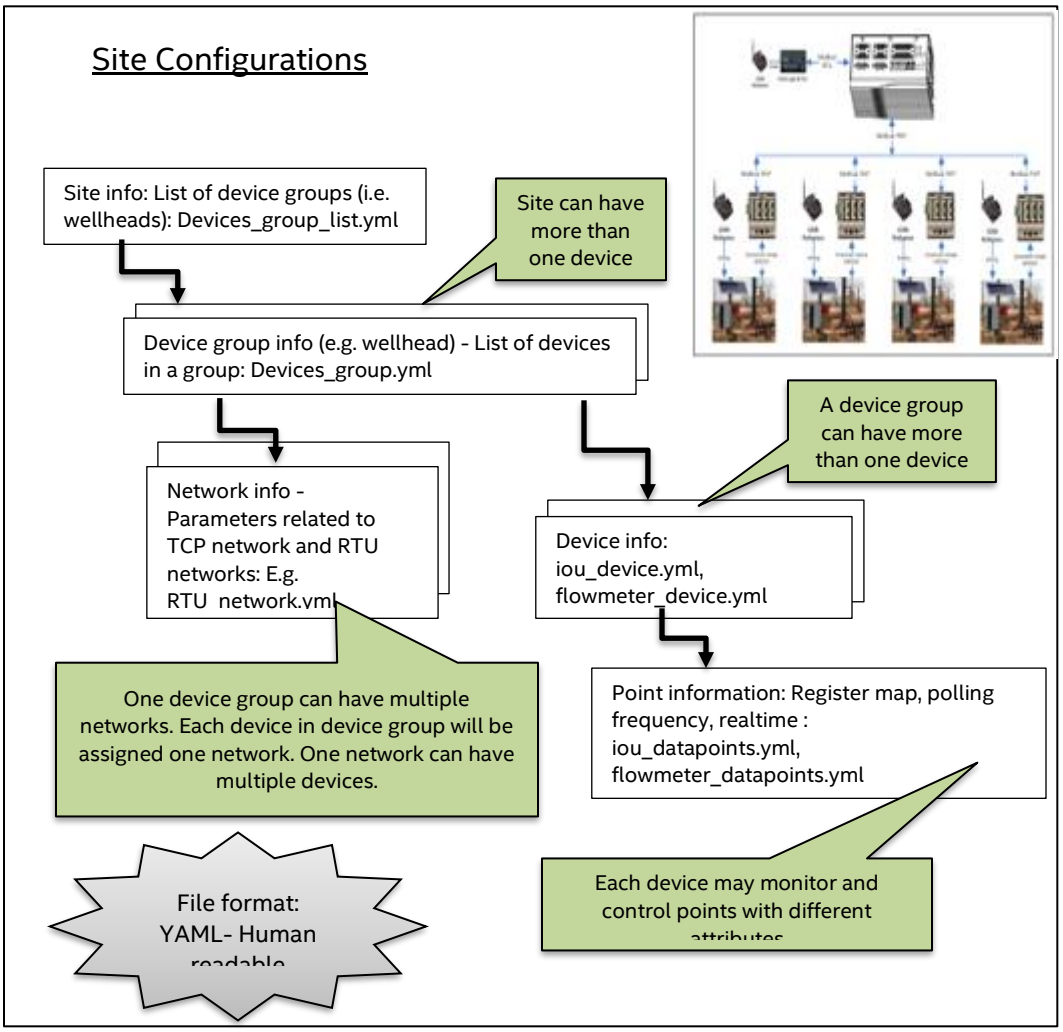
2.2 Upstream Oil and Gas Facilities

The example provided for UWC in this Guide is for a natural gas wellhead with one or more wells. The wellhead will have several field devices often using the Modbus protocols (both TCP and RTU). A Modbus device will have number of points to be read and/or written. The table below shows how wellhead, device, and points are related to each other.

Wellhead	**Device**	**Point**
WellHead1	flowmeter1	KeepAlive
		Flow1
	iou	AValve
WellHead2	flowmeter2	KeepAlive
WellHead3	iou	BValve

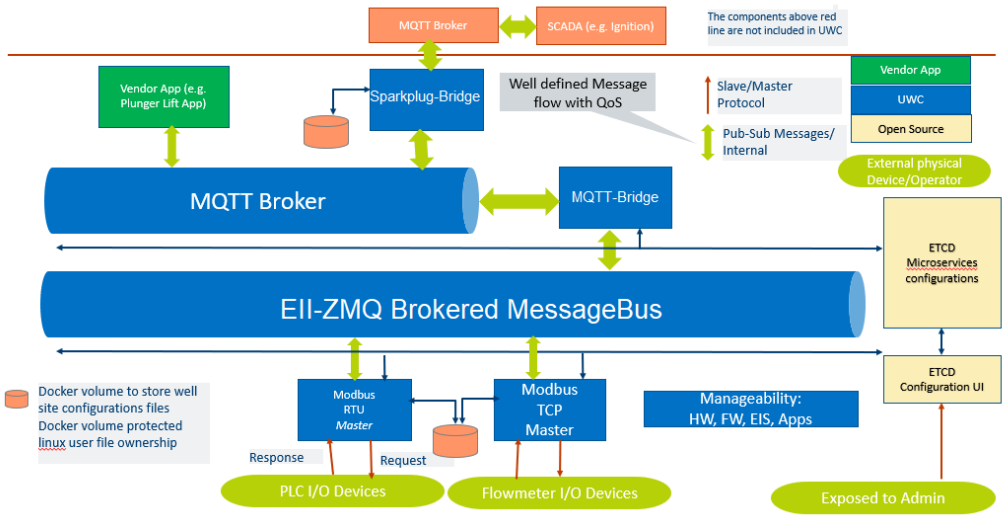
There could be similar devices and similar points in different wellheads. Hence, UWC uses this hierarchy to uniquely name a point. A point is identified like "/device/wellhead/point" e.g., flowmeter1/WellHead1/KeepAlive

UWC defines a data model which can be used to describe the hierarchy of wellhead, device, and points.


Site Configurations
Site info: List of device groups (i.e. wellheads): Devices_group_list.yml
Site can have more than one device
Device group info (e.g. wellhead) - List of devices in a group: Devices_group.yml
A device group can have more than one device
Network info - Parameters related to TCP network and RTU networks: E.g. RTU network.yml
Device info: iou_device.yml, flowmeter_device.yml
One device group can have multiple networks. Each device in device group will be assigned one network. One network can have multiple devices.
Point information: Register map, polling frequency, realtime : iou_datapoints.yml, flowmeter_datapoints.yml
File format: YAML- Human
Each device may monitor and control points with different

2.3 Understanding UWC Platform

Following is a high-level block diagram of UWC:



The application can subscribe to MQTT topics to receive polled data. Similarly, the application can publish data to be written on MQTT. The platform will accordingly publish or subscribe to respective topics. The MQTT topics to be used can be configured.

Internally, UWC platform uses a message bus (called ZMQ) for which the topics need to be configured. ZMQ is not shown above for ease of understanding.

2.3.1 Modbus containers

UWC supports Modbus TCP master and Modbus RTU master for communicating with Modbus client devices present in a field. These are developed as two separate containers i.e., Modbus TCP container and Modbus RTU container. Please refer diagram in section 2.3.

1. Modbus RTU master container

Modbus RTU devices can be connected using RS485 or RS232. Normally, with RS232, only one device is connected at one time. Hence, to communicate with two Modbus RTU devices over RS232, two different serial ports will be needed.

Modbus RTU protocol with RS485 physical transport uses a twisted pair of wires in a daisy-chain shared media for all devices on a chain. The communications parameters of all devices on a chain should be the same, so if, different devices have different configuration (e.g., different parity, different baud rate, etc.), then, different Modbus RTU chains can be formed. To communicate with two different Modbus RTU networks, two different serial ports will be needed. It is important to verify the analog signal integrity

of the RS-485 chains including the use of termination resistors as per well-known RS-485 best-practices.

In UWC, one Modbus RTU master can be configured to communicate over multiple serial ports. Hence a single Modbus RTU master container handles communication with multiple Modbus RTU networks. The configuration for one Modbus RTU network (e.g., port, baud rate, etc.) can be configured in a RTU network configuration file, explained in later section of this document.

2.3.2 MQTT-Bridge container

Modbus containers communicate over ZMQ. The MQTT-Bridge module enables communication with Modbus containers using MQTT. The MQTT- Bridge module reads data on ZMQ received from Modbus containers and publishes that data on MQTT. Similarly, the MQTT- Bridge module reads data from MQTT and publishes it on ZMQ.

This module was earlier known as MQTT-Export.

2.3.3 Sparkplug-Bridge container

UWC supports Eclipse Foundation's Sparkplug standard to expose data to SCADA Master over MQTT. Sparkplug-Bridge implements the standard and enables communication with SCADA Master. This module was earlier known as SCADA-RTU.

This module exposes the data on the platform to an external, centralized, master system for the SCADA:

- Data from base UWC platform i.e., real devices
- Mechanism to expose data from Apps running on UWC i.e., virtual devices.

1. Sparkplug MQTT Topic Namespace

Following is the topic format:
`spBv1.0/group_id/message_type/edge_node_id/[device_id]`

`group_id`

The group_id element of the Sparkplug™ Topic Namespace provides for a logical grouping of MQTT EoN nodes into the MQTT Server and back out to the consuming MQTT Clients. The value should be descriptive but as small as possible.

The value of the group_id can be valid UTF-8 alphanumeric string. The string shall not use the reserved characters of '+' (plus), '/' (forward slash), and '#' (number sign).

The value of this field can be configured in a configuration file (link).

`message_type`

The message_type elements are defined for the Sparkplug™ Topic Namespace. The values could be:

- NBIRTH – Birth certificate for MQTT EoN nodes.
- NDEATH – Death certificate for MQTT EoN nodes.
- DBIRTH – Birth certificate for Devices.
- DDEATH – Death certificate for Devices.
- NDATA – Node data message.
- DDATA – Device data message.
- NCMD – Node command message.
- DCMD – Device command message.
- STATE – Critical application state message.

`edge_node_id`

The edge_node_id element of the Sparkplug™ Topic Namespace uniquely identifies the MQTT EoN node within the infrastructure. The group_id combined with the edge_node_id element must be unique from any other group_id/edge_node_id assigned in the MQTT infrastructure. The topic element edge_node_id travels with every message published and should be as short as possible.

The value of the edge_node_id can be valid UTF-8 alphanumeric string. The string shall not use the reserved characters of '+' (plus), '/' (forward slash), and '#' (number sign).

The value of this field can be configured in a configuration file (link).

`device_id`

The device_id element of the Sparkplug™ Topic Namespace identifies a device attached (physically or logically) to the MQTT EoN node. The device_id must be unique from other devices connected to the same EoN node. The device_id element travels with every message published and should be as short as possible.

The format of the device_id is a valid UTF-8 alphanumeric String. The string shall not use the reserved characters of '+' (plus), '/' (forward slash), and '#' (number sign).

2. Supported message types

Following message types are supported in current version of UWC:

Message Type	Support for real device	Support for virtual device (apps)
NBIRTH	Supported. This is an edge level message.	
NDEATH	Supported. This is an edge level message.	

DBIRTH	Supported. Data is taken from YML file.	Supported. Vendor app should publish data on “BIRTH” topic.
DDATA	Supported. Data from Poll-update messages is taken to determine change in data for publishing a DDATA message	Supported using RBE (Report By Exception). Vendor app should publish data on “DATA” topic.
DCMD	Supported. A corresponding On-Demand-Write request message is published on internal MQTT for other UWC containers to process a request.	Supported. A corresponding CMD message is published on internal MQTT for vendor app.
DDEATH	Supported. Data from Poll-update messages is taken to determine change in data for publishing a DDEATH message in case of error scenarios	Supported. Vendor app should publish data on “DEATH” topic.
NDATA	Not Supported	
NCMD	Supported “Node Control/Rebirth” control	
STATE	Not Supported	

3. Name of edge node

User should properly configure “`group_id`” and “`edge_node_id`” for each edge gateway deployed in a site such that each edge node can be uniquely identified.

2.3.4 KPI Application container

A sample application provided with the UWC package is the Key Performance Indicator (KPI) Application. The KPI Application is provided for two purposes:

1. Small microservice has a set of features that will be used in many end-user services including interfaces to the 0MQ and MQTT message buses, it writes to log files, and accesses the reference time of the system. The application consumes polled read data from the bus and publishes on-demand writes to the bus.

2. The application creates a set of read and write data patterns that can simply be used to predict and characterize the performance of the UWC to execute “discrete-time, single input, single output” control loop(s). Within the UWC, a discrete-time process control loop with modbus-connected sensor and actuator is implemented by a RT.

Polled read from the sensor, followed by the control model in a user-defined microservice, which then generates the on-demand RT write back to the actuator. This loop is repeated on the schedule of the on-demand read function in a consistent and timely fashion. In the simple KPI Application no control model logic is provided, instead a user-configurable fixed delay (e.g., 5 milliseconds) is applied between the receipt of the read data and the initiation of the on-demand write. One or more loops can be defined. The KPI Application logs all data received as a part of control loop application in a log file. This data can be used for measuring performance of the system.

This KPI Application can either be executed based on MQTT communication or based on ZMQ communication. Please refer configurations for more details.

2.3.5 Configurations

The KPI application can be used with real external Modbus devices (pressure, flow, level, or other sensors) and actuators (variable position valves, on/off relief valves, etc.) or it can be used with Modbus emulators which simply can handle the read and write operations. The developer can insert their own control model (e.g., PID control loop function) and quickly evaluate the UWC in a test bed with their real physical system.

UWC needs following configuration to function properly:

- Information about device group list (i.e., wellhead), device and points falling under respective Modbus container.
- Information about topics for internal message queue, publishers, and subscribers

All these configurations are related and depend on the hierarchy of wellhead, devices, and point.

Following sections detail the UWC installation, configuration process.

3.0 Installation Guide

3.1 How to install UWC software with EII installer

This section provides steps to install and Deploy UWC containers using EII installer.

Pre-requisite: Internet connection (With proper Proxy Settings, if any) is required for Installation.

Steps:

1. Install Ubuntu 18.04 server version on gateway and Apply RT Patch (refer section 13).
2. Git clone in following order will place the directories in proper relative directory structure.
   - git clone https://github.com/open-edge-insights/eii-core.git IEdgeInsights --branch=v2.5.1
   - git clone https://github.com/open-edge-insights/eii-messagebus.git IEdgeInsights/common/libs/EIIMessageBus --branch=v2.5
   - git clone https://github.com/open-edge-insights/eii-c-utils.git IEdgeInsights/common/util/c --branch=v2.5
   - git clone https://github.com/open-edge-insights/eii-zmq-broker.git IEdgeInsights/ZmqBroker --branch=v2.5
   - git clone https://github.com/open-edge-insights/uwc.git IEdgeInsights/uwc --branch=v1.5
   - git clone https://github.com/open-edge-insights/uwc-docs.git IEdgeInsights/uwc-docs --branch=v1.5
3. Navigate to `$ <working_dir>/IEdgeInsights/build`
4. Execute Command
   a. `$./pre_requisites.sh -proxy`=<proxy address with port number> for proxy enabled network.
   b. `$ sudo ./pre_requisites.sh` – for non-proxy network
5. Navigate to "<working_dir>/IEdgeInsights/uwc/build_scripts.sh
6. Execute Command `$ sudo ./01_uwc_pre_requisites.sh`
7. Execute Command `$ sudo ./02_provision_UWC.sh`

It prompts below options –

- Please choose one of the below options based on Dev or Prod mode.
  1) Dev
  2) Prod

- Please choose one of the below options based on the use case (combination of UWC services) needed.

1) Basic UWC micro-services without KPI-tactic Application & Sparkplug-Bridge - (Modbus-master TCP & RTU, mqtt-bridge, internal mqtt broker, ETCD server, ETCD UI & other base EII & UWC services)
2) Basic UWC micro-services as in option 1 along with KPI-tactic Application (Without Sparkplug-Bridge)
3) Basic UWC micro-services & KPI-tactic Application along with Sparkplug-Bridge
4) Basic UWC micro-services with Sparkplug-Bridge and no KPI-tactic Application

Following is a sample output for Sparkplug-Bridge related configuration:

- Enter the following parameters required for sparkplug-bridge container.

```
Is TLS required for sparkplug-bridge (yes/no): yes

Enter the CA certificate full
path including file
name:/home/ubuntu/new/ca/root-
ca.crt

Enter the client certificate full
path including file name:
/home/ubuntu/new/client/client.crt

Enter the client key certificate full
path including file name:
/home/ubuntu/new/client/client.key

Enter the external broker address/hostname:192.168.1.11

Enter the external broker port number: 22883

Enter the QOS for scada (between 0 to 2): 1
```

- Enter the following parameters required for sparkplug-bridge container.

```
Is TLS required for sparkplug-bridge (yes/no): no

Enter the external broker address/hostname:192.168.1.11

Enter the external broker port number: 22883

Enter the QOS for scada (between 0 to 2): 1
```

8. Execute Command `$ sudo ./03_Build_Run_UWC.sh`

Above is a process for interactive mode. A non-interactive mode is also supported. Following are the details:

9. To support non-interactive mode, following options are added to 2nd script (`02_provision_UWC.sh`).

Argument	Values	Description
`--deployMode`	dev or prod	Deployment mode to be used.
`--recipe`	1 or 2 or 3 or 4	Recipe file to be referred for provisioning: 1: Basic UWC micro-services without KPI-tactic app & Sparkplug-Bridge 2: Basic UWC micro-services as in option 1 along with KPI-tactic app 3: Basic UWC micro-services & KPI-tactic app along with Sparkplug-Bridge 4: Basic UWC micro-services with Sparkplug-Bridge and no KPI-tactic
`--isTLS`	yes or no	This option is applicable for Sparkplug-Bridge (i.e., value of "--recipe" is 3 or 4). It tells whether communication with external broker is secured or not.
`--cafile`	File path	This option is applicable for Sparkplug-Bridge (i.e., value of "--recipe" is 3 or 4) and when "--isTLS" is "yes". Root CA file path
`--crtfile`	File path	This option is applicable for Sparkplug-Bridge (i.e., value of "--recipe" is 3 or 4) and when "--isTLS" is "yes". Client certificate file path

`--keyFile`	File path	This option is applicable for Sparkplug-Bridge (i.e., value of "-- recipe" is 3 or 4) and when "--isTLS" is "yes". Client key file path
`--qos`	0 or 1 or 2	This option is applicable for Sparkplug-Bridge (i.e., value of "-- recipe" is 3 or 4). It tells QOS value to be used for MQTT communication.
`--brokerAddr`	String	This option is applicable for Sparkplug-Bridge (i.e., value of "-- recipe" is 3 or 4). It tells address to be used for external broker communication.
`--brokerPort`	Number	This option is applicable for Sparkplug-Bridge (i.e., value of "-- recipe" is 3 or 4). It tells port number to be used for external broker communication.

If required parameters are missing, then those will be requested from user in an interactive mode.

10. Following are sample commands for non-interactive mode execution.

    All UWC basic modules (no KPI, no Sparkplug-Bridge)
    ```
    sudo ./02_provision_UWC.sh --deployMode=dev --recipe=1
    ```

    All UWC modules (with KPI and with Sparkplug-Bridge).
    ```
    sudo ./02_provision_UWC.sh --deployMode=dev --recipe=3 --
    isTLS=yes --caFile="scada_ext_certs/ca/root-ca.crt" --
    crtFile="scada_ext_certs/client/client.crt" --
    keyFile="scada_ext_certs/client/client.key" --
    brokerAddr="192.168.1.11" --brokerPort=22883 --qos=1
    ```

Build scripts descriptions–

1. 01_uwc_pre_requisites.sh - This script creates docker volume directory /opt/intel/eii/uwc_data, creates “/opt/intel/eii/container_logs/” for storing log and git clone modconn into respective directory of modbus master container.
2. 02_provision_UWC.sh - It runs the builder to generate consolidated docker-compose.yml. This script performs provisioning as per docker-compose.yml file. Along with this, it generates certs for mqtt.
   It allows user to choose combination of UWC services, allows to choose deployment mode either dev or prod mode.
3. 03_Build_Run_UWC.sh - This script will build and deploys all UWC containers.
4. 04_uninstall_UWC.sh – Used for cleanup and uninstalling docker, docker-compose and installed libraries. This script will bring down all containers and removes all running containers.

5. 05_applyConfigChanges.sh - This script will stop and start all running containers with updated changes.
6. 06_UnitTestRun.sh - This script will generate unit test report and code coverage report.

4.0 After Installation

4.1 Deactivate Auto Update

Once all the containers are deployed successfully, please disable system's auto update feature as specified in the below sections. Auto update feature is enabled by default in Ubuntu.

These steps are optional. It is needed to switch off auto updates of packages (Package-Lists, periodic etc) when connected to internet.

4.1.1 Deactivate Unattended Upgrades

To deactivate unattended upgrades, we need to edit */etc/apt/apt.conf.d/20auto-upgrades* file and do the following changes.

1. Disable update package list by changing setting

   from *APT::Periodic::Update-Package-Lists* **"1"**

   to *APT::Periodic::Update-Package-Lists* **"0"**

2. Disable unattended upgrade by changing setting

   from *APT::Periodic::Unattended-Upgrade* **"1"**

   to *APT::Periodic::Unattended-Upgrade* **"0"**

4.1.2 Deactivate Periodic Unattended Upgrades

To deactivate periodic unattended upgrades, we need to

edit */etc/apt/apt.conf.d/10periodic* file and do the following changes

1. Disable update package list by changing setting

   from `APT::Periodic::Update-Package-Lists` **"1"** to

   to `APT::Periodic::Update-Package-Lists` **"0"**

2. Disable download upgradable packages by changing setting

   from *APT::Periodic::Download-Upgradeable-Packages* **"1"**

   to *APT::Periodic::Download-Upgradeable-Packages* **"0"**

3. Disable auto clean interval by changing setting

from *APT::Periodic::AutocleanInterval* **"1"**

to *APT::Periodic::AutocleanInterval* **"0"**

4.1.3 Deactivate Scheduled Upgrades

To deactivate scheduled download please execute below commands.

1. `sudo systemctl stop apt-daily.timer`
2. `sudo systemctl disable apt-daily.timer`
3. `sudo systemctl disable apt-daily.service`
4. `sudo systemctl daemon-reload`

5.0 Container Configuration settings

This section provides details about configuring UWC containers.

5.1 Containers

Following containers are developed under UWC:

- Modbus TCP Master
- Modbus RTU Master
- MQTT-Bridge
- MQTT
- Sparkplug-Bridge
- KPI Application

For configuring these containers, docker-compose.yml file is used. The docker-compose.yml is auto generated based on inputs provided while executing script 02_provision_UWC.sh.

For more details, please refer README provided in EII documentation.

Path for README – https://github.com/open-edge-insights/eii-core/blob/master/README.md

UWC containers (i.e., Modbus Clients and MQTT-Bridge) use ZeroMQ to communicate with each other.

At present, recommendation is to have only one Modbus-TCP and one Modbus-RTU container. Hence, changes to configuration present in docker-compose.yml file shall not be needed.

5.1.1 Common Configuration for Modbus Client Containers

Following are configurations, applicable for Modbus Client (TCP and RTU both) containers:

Configuration Parameter	Description
MY_APP_ID	Unique ID assigned to a container. It can have values from 0 to 15.
CUTOFF_INTERVAL_PERCENTAGE	Modbus container will send a Bad response if a response is not received from end device for a point in a polling cycle during this cutoff time. (See section 6 for Message formats including Bad messages and see section 8 for error codes associated with Bad responses.) The cutoff time is defined in terms of percentage of a polling interval. Default value is 90%. So, if polling interval is 1000 ms then cutoff time is 900 ms. This configuration allows to change default setting.
DEVICES_GROUP_LIST_FILE_NAME	Name of devices group list file to be used to obtain information of wellheads, device, datapoints handled by this container.

Example for Modbus-TCP-Master container from docker-compose.yml file:

```
                AppName: "TCP"
                ETCD_HOST: ${ETCD_HOST}
                ETCD_CLIENT_PORT: ${ETCD_CLIENT_PORT}
                ETCD_PREFIX: ${ETCD_PREFIX}
                DEV_MODE: ${DEV_MODE}
                no_proxy: ${eii_no_proxy}
                Log4cppPropsFile:
        "/opt/intel/config/log4cpp.properties"
                MY_APP_ID: 1
                CUTOFF_INTERVAL_PERCENTAGE: 90
                CertType: "zmq"
                PROFILING_MODE: ${PROFILING_MODE}
                NETWORK_TYPE: TCP
                DEVICES_GROUP_LIST_FILE_NAME:
        "Devices_group_list.yml"
```

5.1.2 Configuration for Modbus Network

A separate network configuration YML file is maintained for each network. E.g., If there are 2 RTU and 1 TCP networks, then there will be 3 network configuration files. This file contains following configuration for both TCP and RTU:

```
# inter-frame delay and response timeout values are in
Millisecond
interframe_delay: 1
response_timeout: 80
```

For Modbus RTU master, following additional configurations are needed apart from above mentioned parameters:

```
baudrate: 9600
parity: "N"
com_port_name: "/dev/ttyS0"
```

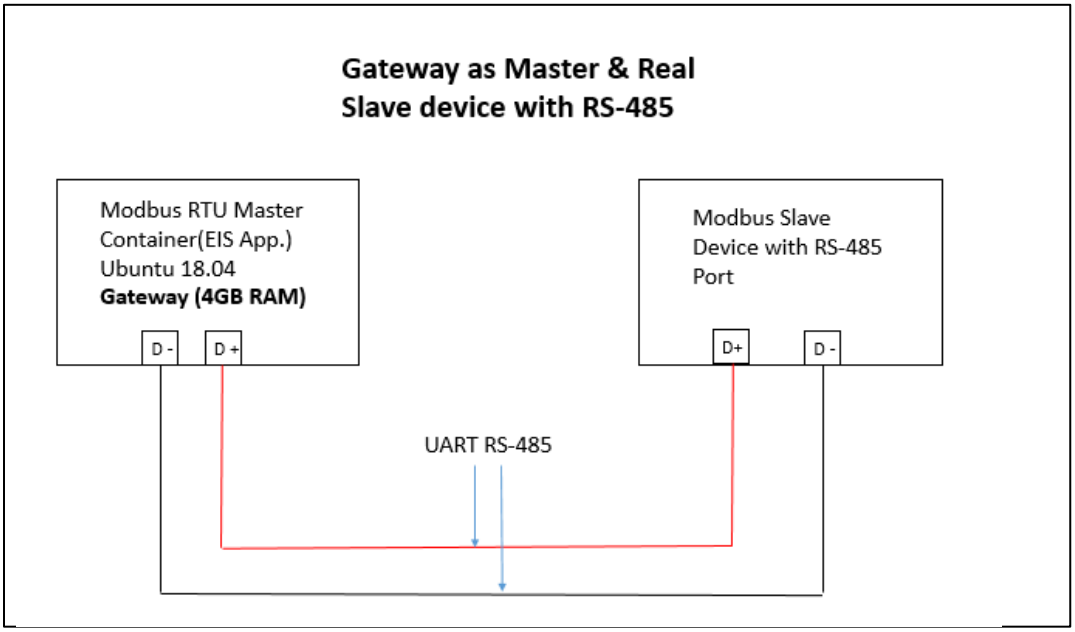
Configuration Parameter	Description
BAUD_RATE	Baud rate used for this Modbus RTU network and port.
PARITY	Parity to be used to communicate for this Modbus RTU network. Values are: “N” for none, “O” for odd, “E” for even
PORT_NAME	Serial port to be used to communicate for this Modbus RTU network
response_timeout	Maximum time (in milliseconds) to wait to receive a response from end device for a request
interframe_delay	Additional delay (in milliseconds) to wait for before sending a next request to the device. For Modbus RTU, next request is sent only after previous request has timed out or a response for previous request is received. This additional delay is added when sending a next request. For Modbus TCP, a next request to the device is sent irrespective of response for previous request. This additional delay is added when sending a next request.

5.2 Modbus TCP Communication

When used in TCP mode, the publisher of a stream will bind to a TCP socket and the subscribers connect to it to receive data. In Request-Response pattern, the responder acts as the server and binds the socket and the requester connects to it.

5.3 Modbus RTU Communication

Modbus RTU is an open serial protocol derived from the Master/Slave architecture. UWC Modbus-rtu-container is used as master and slave can be configured.



Please note: To communicate with slave device, Modbus RTU mater uses configuration parameters (i.e., baud rate, parity, stop bits) from docker-compose.yml file.

5.4 MQTT Bridge

This container is used to send messages from ZeroMQ to MQTT and vice-versa.

Modbus containers communicate over the internal Edge Insights for Industrial data bus (ZMQ). The MQTT-Bridge module enables communication with Modbus containers using MQTT. The MQTT- Bridge module reads data on ZMQ received from Modbus containers and publishes that data on MQTT. Similarly, the MQTT- Bridge module reads data from MQTT and publishes it on ZMQ.

5.5 MQTT

The MQTT container is a mosquitto broker required for MQTT to publish/subscribe data. MQTT broker use port "11883".

MQTT clients should use above mentioned port for communication.

5.5.1 Accessing secured MQTT container from an external MQTT client

Pre-requisites:

All UWC containers must be deployed-on gateway with DEV_MODE=false (i.e., secured mode).

Steps to follow:

1. Open a terminal and execute following command to create local directory to keep certificates of MQTT broker,

   ```
   mkdir ~/mqtt_certs && cd ~/mqtt_certs
   ```

   Copy ca/ and /mymqttcerts directories in local directory i.e., created in script `02_provision_UWC.sh` from `working_dir/IEdgeInsights/build/provision/Certificates/` directory.

   Command to copy ca/ and /mymqttcerts/ dir in local dir (i.e., `mqtt_certs`)

   ```
   sudo cp -r
   /<working_dir>/IEdgeInsights/build/provision/Certificat
   es/ca ~/mqtt_certs/
   ```

2. Assign read permission to local certs using following command,

   ```
   sudo chown -R $USER:$USER * && sudo chmod +r ca/*
   mymqttcerts/*
   ```

   Please Note: Read permissions are only required for `ca/` and `/mymqttcerts` directories present inside `mqtt_certs` directory copied in step2.

   Provide right access to certificates directory using below command – `sudo chmod +x Certificates` in

   ```
   <working_dir>/IEdgeInsights/build/provision/Certificates
   ```

3. Open MQTT client e.g., MQTT.fx

Container Configuration settings

4. Open the connection setting and click on SSL/TLS tab.

   >> then click on Self Signed certificate option >> select CA file from `mqtt_certs/ca` directory (file name : ca_certificate.pem) , Client Certificate file from `mqtt_certs/mymqttcerts` directory (File name : mymqttcerts_client_certificate.pem) and Client key File from `mqtt_certs/mymqttcerts` directory (File name : mymqttcerts_client_key.pem) copied in step 2

5. Click on PEM Formatted check box and then save the setting and then connect. Refer below screenshot for more details

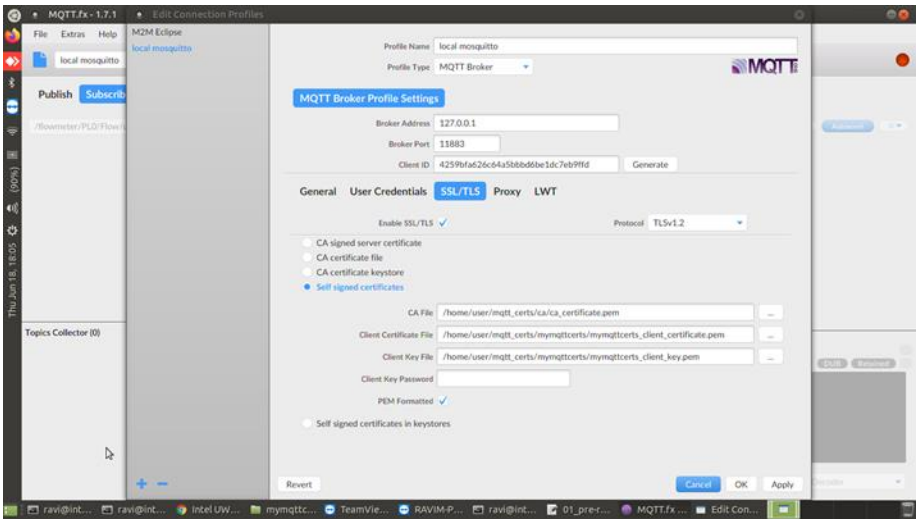


Figure 1 : Screen capture for mqtt.fx client connection

5.5.2 Accessing secured MQTT container from a client inside a container

1. Mention following secrets for a new container in docker-compose.yml file.

   - ca_broker – CA certificate
   - client_cert – Client certificate
   - client_key – Client Key

Following sample snippet for docker-compose.yml file

```
secrets:
  - ca_broker
  - client_cert
  - client_key
```

2. Use certificates mentioned in step 1 inside application to connect with secured MQTT broker which is running as a part of UWC.

   Following is the sample code snippet in C++ to use certificates in a program,

```
mqtt::ssl_options sslopts;
sslopts.set_trust_store("/run/secrets/ca_broker");
sslopts.set_key_store("/run/secrets/client_cert");
sslopts.set_private_key("/run/secrets/client_key");
sslopts.set_enable_server_cert_auth(true);
syncConnOpts.set_ssl(sslopts);
```

3. Deploy containers using usual deployment process.

5.6 Sparkplug-Bridge

This container implements Eclipse Foundation's SparkPlug standard to expose data to compliant SCADA Master over MQTT.

5.6.1 Pre-requisite for running Sparkplug-Bridge

a) SCADA Master (e.g., Ignition System) shall be installed and configured.

b) MQTT broker shall be installed and configured in SCADA Master. At present secured connectivity for MQTT is not supported.

c) Following parameters should be configured for Sparkplug-Bridge in docker-compose.yml file:

DEVICES_GROUP_LIST_FILE_NAME	Name of devices group list file to be used to obtain information of wellheads, device, datapoints reported by this container as real devices to SCADA Master.

5.7 KPI App

This is a sample application which implements control loops and logs data in a log file named “AnalysisKPIApp.log”. Normally 3 log files are created on rolling basis i.e., once tie set file size limit is exceeded, a new file is created and likewise max 3 files are created. After this, the log files are overwritten.

The log file size can be updated, if required.

File: log4cpp.properties

Path in release package: kpi-tactic\KPIApp\Config

Path after deployment inside container: /opt/intel/config/log4cpp.properties

Log files created are - AnalysisKPIApp.log, AnalysisKpiApp.log1, and AnalysisKpiApp.log2. These files are created in .txt format. Latest data will be available in AnalysisKPIApp.log followed by AnalysisKpiApp.log1, and AnalysisKpiApp.log2

Default log file size is around 34mb.

```
log4cpp.appender.analysis.fileName=AnalysisKPIApp.log
log4cpp.appender.analysis.maxFileSize=34603008
```

To change the file size, “log4cpp.properties” needs to be changed. Please change the limit highlighted above. The max file size mentioned here is in bytes. Please identify number of bytes as per file size needed and set the value here.

Please run script 03_Build_Run_UWC.sh after changing “log4cpp.properties”.

6.0 Site Configurations

This section provides configurations required to configure site, wellhead, device and points for UWC containers.

6.1 System Level Global Configuration

This file contains configuration to be used for operations across UWC containers for (Modbus-TCP, Modbus-RTU, MQTT-Bridge.)

Global_Config.yml file location - /opt/intel/eii/uwc_data/common_config

Based on realtime requirement, operations are classified into following sub-operations

1. Polling realtime

2. Polling non-realtime

3. On-demand read realtime

4. On-demand read non-realtime

5. On-demand write realtime

6. On-demand write non-realtime

7. SparkPlug communication for Sparkplug-Bridge

8. default scale factor

6.1.1 Settings for Polling and On-Demand operation

Following is a sample for Polling operation. Similar is applicable for On-demand operations:

```
Global:
    Operations:
        - Polling:
            default_realtime: false
            realtime:
              operation_priority: 4
              retries: 1
              qos: 1
            non-realtime:
              operation_priority: 1
              retries: 0
              qos: 0
```

Following is a description of each field.

Field	Values	Description
`default_realtime`	`true` or `false`	It defines how an operation should be performed in absence of corresponding realtime indicator. E.g. In case of on-demand-write or read request, the json payload contains a field called "realtime". This field defines realtime nature in absence of such a field in on-demand request or polling configuration
`realtime`		This is a group field. Defines configuration for realtime operation.
`non-realtime`		This is a group field. Defines configuration for realtime operation.
Sub fields for "`realtime`" and "`non-realtime`" group		
`operation_priority`	1 to 6	The field defines priority to be assigned to 6 sub-operations (related to Polling and On-Demand), listed above. 1 is lowest priority and 6 is highest priority. Hence, if there are 2 requests ready for execution, a request with higher priority will be executed first.
`retries`	0 to 4	This field specifies if a request of particular type should be resent if a response is not received within specified limit. Value 0 means no retry is needed. value 1 means, retry once.

`qos`	0 or 1 or 2	MQTT-Bridge will use this QoS value while publishing a message on MQTT.

If incorrect value is specified for any of above fields, a default value (listed below) will be used:

```
default_realtime: false
operation_priority: 1
retries: 0
qos: 0
```

If configuration parameter or section is missing for any of the sub-operation (related to Polling and On-Demand), then default values mentioned above will be used.

6.1.2 Settings for Sparkplug-Bridge – SparkPlug communication operation

Following is a sample:

```
Global:
    Operations:
        - SparkPlug_Operation:
            group_id: "UWC nodes"
            edge_node_id: "RBOX510"
```

Above are also the default values for mentioned parameters. If configuration parameter or section is missing for SparkPlug communication, then default values mentioned above will be used.

The parameters here are used to form SparkPlug formatted topic name.

These values should properly be configured to ensure correct representation of data under SCADA Master.

Following is a description of each field.

Field	Values	Description
`group_id`	String	It defines value to be used for “group_id” element in the Sparkplug™ Topic Namespace. Example value “Huston Site”.
`edge_node_id`	String	It defines value to be used for “edge_node_id” element in the Sparkplug™ Topic Namespace. Example value “Node 1”.

6.1.3 Settings for default scale factor

Following is a sample:

```
Global:
    Operations:
      .
      .
      .
default_scale_factor: 1.0
```

Field	Values	Description
`default_scale_factor`	Positive, negative, decimal values except 0	Original value can be scaled up or scaled down using this parameter. This parameter's value is considered when data point scale factor is not available in datapoint.yml. This parameter can have positive, negative, decimal values except 0. E.g., 5, -5, 12.34. Default value of this parameter is 1.0.

6.2 How to Configure Site and Wellhead

There is one file which lists down reference to device-groups (i.e., wellheads) controlled by one UWC gateway. Ideally, in one UWC gateway there is one TCP and one RTU container. Please note one RTU container can manage communication with multiple RTU networks.

```
---
file:
  version: "1.0.0"
  author: "Intel"
  date: "Sun Sep 1 13:34:13 PDT 2019"
  description: "Common device group file for TCP and RTU devices"
devicegrouplist:
- "Device_group1.yml"
- "Device_group2.yml"
```

Above example shows "Device_group1" and "Device_group2" as a reference to group of devices. "`Device_group1.yml`" is a separate file listing down all TCP and RTU devices falling under one device-group (e.g. wellhead PL0)

Each device-group file will have information about devices in that group.

```
---
file:
```

```
  version: "1.0.0"
  author: "Intel"
  date: "Sun Sep 1 13:34:13 PDT 2019"
  description: "Device group 1"
id: "PL0"
description: "Device group 1"
devicelist:
- deviceinfo: "flowmeter_device.yml"
  id: "flowmeter"
  protocol:
    protocol: "PROTOCOL_TCP"
    ipaddress: "192.168.0.222"
    port: 502
    unitid: 1
  tcp_master_info: "tcp_master_info.yml"

- deviceinfo: "iou_device.yml"
  id: "iou1"
  protocol:
    protocol: "PROTOCOL_RTU"
    slaveid: '10'

  rtu_master_network_info: "rtu_network1.yml"
```

Following sections provide details about TCP and RTU device configuration in device-group file.

6.2.1 Configuring TCP device in device-group

E.g.

```
devicelist:
- deviceinfo: "flowmeter_device.yml"
  id: "flowmeter"
  protocol:
    protocol: "PROTOCOL_TCP"
    ipaddress: "192.168.0.222"
    port: 502
    unitid: 1
  tcp_master_info: "tcp_master_info.yml"
```

Following parameters are needed for each TCP device:

- ipaddress – for TCP communication IP address for slave device required
- port – can be configured as per slave device configuration
- unitid – id can used to distinguish multiple slaves on same ipaddress

- tcp_master_info - tcp_master_info.yml – In this file interframe delay and response timeout can be configured for TCP network

Following is a sample file for tcp_master_info.yml

```
file:
    version: "1.0.0"
    author: "Intel"
    date: "Sun Sep 1 13:34:13 PDT 2019"
    description: "TCP master config parameter file"

# inter-frame delay and response timeout values are in
Millisecond
interframe_delay: 1
response_timeout: 80
```

Note: This reference shall be unique across TCP devices and needs to be given for each TCP device.

6.2.2 Configuring RTU device in device-group

E.g.

```
devicelist:
- deviceinfo: "iou_device.yml"
  id: "iou1"
  protocol:
    protocol: "PROTOCOL_RTU"
    slaveid: '10'
  rtu_master_network_info: "rtu_network1.yml"
```

Following parameters are needed for each RTU device:

- slaveid – This is end device id in case of RTU communication
- rtu_master_network_info: "rtu_network1.yml" – This file is used to configure RTU configuration for a specific RTU network.

Following is a sample file for rtu_network1.yml

```
---
file:
    version: "1.0.0"
    author: "Intel"
    date: "Sun Sep 1 13:34:13 PDT 2019"
    description: "RTU Network information for network 1"
baudrate: 9600
parity: "N"
com_port_name: "/dev/ttyS0"

# inter-frame delay and response timeout values are in Millisecond
```

```
interframe_delay: 1
response_timeout: 80
```

Note: This file needs to be specified for each RTU device. If multiple RTU networks are present (RS485/RS232) then those many files should be created. For each RTU device, an appropriate RTU network reference shall be provided.

6.3 How to Configure Devices

Device contains information of a device. Below is a sample file –

```
file:
  version: "1.0.0"
  author: "Intel"
  date: "Sun Sep 1 13:34:13 PDT 2019"
  description: "Information for Demo IOUnit"
device_info:
  name: "IO Unit"
  description: "Power Scout Meter"
  manufacturer: "Dent Instruments"
  model: "PS3037"
pointlist: "iou_datapoints.yml"
```

6.4 How to Configure Device points

Device Point contains end point information. Below is a sample file.

Below parameters can be changed in this file –

- addr - can be of range 0 to 65534
- pollinterval – value in milliseconds
- type – Function Code
- width – Number of bytes to be read
- realtime – To be used for real time, as of date it is false.
- Datatype – Represents data type of the data point.
- Scalefactor – Represents scale factor to be used for the data point.

```
file:
  version: "1.0.0"
  author: "Intel"
  date: "Sun Sep 1 13:34:13 PDT 2019"
  description: "Data for Demo IOUnit data points"
datapoints:
- id: "Arrival"
  attributes:
    type: "DISCRETE_INPUT"
    addr: 2048
    width: 1
    datatype: "boolean"
    scalefactor: 1
  polling:
    pollinterval: 250
```

```
      realtime: true


  - id: "AValve"
    attributes:
      type: "HOLDING_REGISTER"
      addr: 640
      width: 2
      datatype: "INT"
      scalefactor: 1
    polling:
      pollinterval: 1000
      realtime: true


  - id: "DValve"
    attributes:
      type: "COIL"
      addr: 2048
      width: 1
      datatype: "boolean"
      scalefactor: 1
    polling:
      pollinterval: 1000
      realtime: true

  - id: "TubingPressure"
    attributes:
      type: "INPUT_REGISTER"
      addr: 1030
      width: 2
      datatype: "float"
      scalefactor: -1.0
    polling:
      pollinterval: 250
      realtime: true

  - id: "CasingPressure"
    attributes:
      type: "INPUT_REGISTER"
      addr: 1024
      width: 4
      datatype: "double"
      scalefactor: 1.0
    polling:
      pollinterval: 250
      realtime: true

  - id: "KeepAlive"
    attributes:
      type: "COIL"
      addr: 3073
      width: 1
```

```
polling:
  pollinterval: 2000
  realtime: true
```

Note – For coil type width should be 1.

Site Configurations

YML file Configuration table

File Name	Key Name	Value	Optional	Description
Devices_group_list.yml	file:	Contains Key and Values	No	This file contains list of all device groups
	author	Intel	Yes	Author name
	date	Sun Sep 1	Yes	Date
	description	E.g.: Common device group file for TCP and RTU devices	Yes	User can provide description for devices
	version	E.g. "1.0.0"	Yes	Version for device list
	devicegrouplist :	Contains Key and Values	No	It contains device group information. This list can contain multiple groups of devices.
		Device_group1.yml	No	This is to provide device group information
Device_group1.yml	description	Device group 1	Yes	It contains information about all TCP and RTU devices present under one device group
	devicelist:	Contains Key and Values	No	Provides device information
	-deviceinfo:	flowmeter_device.yml	No	Provides id and protocol information
	Id	flowmeter	No	Id of the device
	protocol:	EG- "PROTOCOL_TCP"	No	Protocol information
	ipaddress	192.xx.xx.xx	No	IP Address of Modbus TCP Slave
	port	502	No	Port number of Modbus TCP Slave (Default: 502)
	protocol	PROTOCOL_TCP	No	Hard Coded String
	unitid	1	No	Range 1- 255 (Default: 1)

	tcp_master_info	tcp_master_info.yml	No	This is used to set interframe delay and response timeout for TCP master
	-deviceinfo:	iou_device.yml	No	File Name as a string
	Id	iou	No	String
	protocol	PROTOCOL_RTU	No	Hard Coded String
	slaveid	'10'	No	Range 1- 255.
	rtu_master_network_info	rtu_network1.yml	No	This is network configuration for RTU network in which the RTU slave-device resides.
	author	Intel	Yes	
	date	Sun Sep 1	Yes	
	description	Data for wellhead 1	Yes	
	version	1.0.0	Yes	
	Id	PL0	No	
tcp_master_info.yml	file			This file is used to configure TCP master container
	author	Intel	Yes	
	date	Sun Sep 1	Yes	
	description	TCP master config parameter file	Yes	
	version	1.0.0	Yes	
	interframe_delay	1	Yes	This can be used to add delay (in milliseconds) between consecutive requests
	response_timeout	80	Yes	This is the response timeout (in milliseconds) to be considered for TCP network

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rtu_network1.yml	File			This file is used to set RTU master configuration for Specific network
	author	Intel	Yes	
	Date	Sun Sep 1	Yes	
	description	RTU Network information for network 1	Yes	
	version	1.0.0	Yes	
	baudrate	9600	No	
	Parity	N		
	com_port_name	/dev/ttyS0	No	This is port name for communication
	interframe_delay	1	Yes	This can be used to add delay (in milliseconds) between consecutive requests
	response_timeout	80	Yes	This is the response timeout (in milliseconds) to be considered for RTU network
flowmeter_device.yml	device_info:			This file contains reference to datapoints.yml
	description	Power Scout Meter	Yes	
	manufacturer	Dent Instruments	Yes	
	Model	PS3037	Yes	
	Name	Flowmeter Unit	Yes	
	file:			
	Author	Intel	Yes	

	Date	Sun Sep 1	Yes	
	description			
	Version			
	pointlist	flowmeter_datapoints.yml	No	
flowmeter_datapoints.yml	File			This file contains all information of datapoint. One datapoint YML file corresponds to one SparkPlug template definition. The YML file name (without extension) corresponds to SparkPlug template name.
	Version		No	This is a mandatory field. It should be mapped to the version of SparkPlug template being used.
	-attributes:			
	addr	1	No	Address of Slave device (Range 0- 65535)
	type	COIL	No	Function code String. F.C. 0x01= COIL F.C. 0x02=DISCRETE_INPUT F.C. 0x03=HOLDING_REGISTER F.C. 0x04=INPUT_REGISTER
	width	1	No	Number of Registers (Range 1 to 125)
	Id	Flow	No	Endpoint name of the Slave device.
	wordswap	true	No	Swapping of Registers (2 Byte)
	byteswap	false	No	Swapping of Byte in a Register.
	polling:			
	Pollinginterval	250	No	Polling interval in milliseconds.

	realtime	true	Yes	Value of this field defines whether a point to be polled in realtime or non-realtime mode.
	datatype	“INT”, “UINT”, “float”, “double”, “boolean”, “string”	No	This parameter represents data type of the datapoint. It can be “int”/”INT”, “uint”/”UINT”, “float”, “double”, “boolean” and “string” values. Based on width parameter value datatype’s size is selected. E.g., For integer datatype, when width is 1, it is considered as int16. When width is 2, it is considered as int32. When width is 4, it is considered as int64.
	scalefactor	1.0	Yes	Original value can be scaled up or scaled down using this parameter. This parameter can have positive, negative, decimal values except 0. E.g., 5, -5, 12.34. Default value of this parameter is 1.0.

6.5 How to add/edit/delete new wellhead/device/point configurations

1. User can add/update/edit/delete Oil well configurations files (YML files) from /opt/intel/eii/uwc_data directory.
2. Open a terminal and go to <working_dir>/IEdgeInsights directory.
3. Run below command to apply new Oil well site configurations.

   Navigate to `<working_dir>/IEdgeInsights/uwc/build_scripts`

   ```
   sudo ./05_applyConfigChanges.sh
   ```

   ```
   Note: this script will restart all UWC docker containers
   ```

6.6 KPI App Configuration

Following is a sample configuration file for KPI App.

```
---
file:
  version: "1.0.0"
  author: "Intel"
  date: "Sun Sep 1 13:34:13 PDT 2020"
  description: "KPI App Config File"
```

```
isMQTTModeApp: false

timeToRun_Minutes: 10

isRTModeForPolledPoints: true
isRTModeForWriteOp: true

# This section lists down number of control loops.
# For each control loop, following information is presented:
# 1. Point being polled
# 2. Point and value to be used for writing
# 3. Delay to be used before sending a write operation.
controlLoopDataPointMapping:
- polled_point: "/flowmeter/PL0/P1"
  delay_msec: 5
  write_operation:
    datapoint: "/iou/PL0/D1"
    dataval: "0x01"

- polled_point: "/flowmeter/PL0/P2"
  delay_msec: 15
  write_operation:
    datapoint: "/flowmeter/PL0/D2"
    dataval: "0x1234"
```

Following is a description of each field.

Field	Values	Description
`isMQTTModeApp`	boolean	This field tells whether application runs based on ZMQ or MQTT Default value is false i.e. ZMQ based app. Value can be true or false. Set to true for using MQTT based model.
`timeToRun_Minutes`	Number	This field tells the duration (in minutes) for which this app will run. Set to 0 for no limit. Default value is 0 if this field is missing or has incorrect value.
`isRTModeForPolledPoints`	boolean	This field tells which mode (RT or Non-RT) is used to monitor "polling" in control loop. For ZMQ-based app, RT polling topics will be scanned if set to true.

		This field has no effect in case of MQTT-based app.
`isRTModeForWriteOp`	boolean	This field tells which mode (RT or Non-RT) needs to be used for "write operation" in control loop. When initiating a write request, "realtime" field in JSON payload will be set if RT is needed. For ZMQ-based app, RT write-response topics will be scanned if set to true.
Sub fields for "`controlLoopDataPointMapping`" group		
`polled_point`	String	It defines point to be monitored for "polling" in the control loop.
`delay_msec`	`Number`	It defines delay (in milliseconds) to be used before sending a write operation once polling data is available in a control loop. Default value of delay is 5 msec if this field is missing or has incorrect value.
`write_operation`		This is a group field. It defines all the parameters required to initiate a write request for the control loop.
`Datapoint`	`String`	It defines point to be used for sending "write request" in the control loop.
`Dataval`	`String`	It defines value to be used in "write request" in the control loop.

Please note following: This configuration file should be created manually with following considerations:

A) The points in "`polled_point`" and "`datapoint`" fields in this file should be configured as per actual configuration in wellhead, device and datapoints config files.

   E.g. If a point to be polled is not present in datapoints config file, then data for that control loop will not be collected.

B) If the points being polled are configured as "realtime" in datapoints config file, then "`isRTModeForPolledPoints`" should be set to "`true`". It should be set to "`false`" otherwise.

C) ZMQ-based KPI App can monitor either RT or Non-RT points at a time.

D) KPI App container can run either in ZMQ mode or in MQTT mode at a time.

7.0 UWC Modbus Operations

This section provides configurations required to read and write data from sensors and actuators connected over Modbus TCP or RTU on UWC gateway.

An application can perform following operations using UWC containers:

- Data Polling
- On-Demand Write
- On-Demand Read

Following section explains how to use MQTT topics to perform above operations. Further these operations can be performed in realtime (RT) and non-realtime (Non-RT) mode.

Multiple modules are involved in processing the operation. To capture the time taken by each module (i.e. a step), epoch timestamps in microseconds are added at various levels. These timestamps are present in JSON message.

The table of terms here is useful for interpreting the JSON payloads of the messages.

Key in JSON message	Definition
version	MQTT message format. Value “2.0”
data_topic	This is the MQTT bus topic name. MQTT bus topic is a combination of number of parameters. Topic is explained in respective operation sections – 6.1, 6.2, 6.3
wellhead	Well identifier e.g., PL0
metric	Modbus point e.g., TubingPressure
realtime	It indicates whether the operation to be handled in real-time manner. Values are: 1: Yes 0: No
status	Response status: Good or Bad **Good**: Success response **Bad**: Error response. In case of error response, keys “error_code”, “lastGoodUsec” will be present in json message. Also “value” key will have last known good value, if any.

Key in JSON message	Definition
value	Hex string response for a read operation. E.g., 0x00 This field is not applicable for on-demand-write operation. In case of bad response, this field will represent last know good value, if any.
scaledValue	Scaled value response for a read operation or data polling. This field is not applicable for on-demand-write operation. In case of bad response, this field will represent last known good value, if any.
datatype	Represents data type of the data point.
usec	Epoch timestamp (in microseconds) at which Modbus application container prepares a message to publish on ZMQ.
error_code	This field is present when status is Bad. Refer section 8 for details about error codes.
lastGoodUsec	This field is present when status is Bad. This field represents "usec" timestamp of last known good value, if any.
timestamp	Local system time in human readable format when a message is created
driver_seq	This is applicable for polling operation. The number is assigned automatically by the Modbus Application when a message with polling data is initiated. For each polling message, this field will have different value.
app_seq	This is applicable for on-demand read / write operations. The number is assigned by the application initiating the on-demand operation request. The Modbus Application uses data from on-demand request while sending back the response. This sequence number can be used by application to match response for on-demand request.
Timestamp fields listed below in Time-sequential order	
tsMsgRcvdFromMQTT	This is applicable for on-demand read/ write operation.

Key in JSON message	Definition
	Epoch timestamp (in microseconds) at which message from MQTT is read in MQTT-Bridge.
tsMsgPublishOnEII	This is applicable for on-demand read/ write operation. Epoch timestamp (in microseconds) at which MQTT-Bridge prepares a message to publish on ZMQ.
reqRcvdByApp	This is applicable for on-demand read/ write operation. Epoch timestamp (in microseconds) at which message from ZMQ is read in Modbus application container. MQTT-Bridge sends on-demand request messages to Modbus application over ZMQ.
reqRcvdInStack	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which protocol stack received the request message to send on network. This is step inside Modbus application container.
reqSentByStack	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which protocol stack sends the request message on network. This is step inside Modbus application container.
respRcvdByStack	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which protocol stack reads the response message received from a network. This is step inside Modbus application container.
respPostedByStack	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which protocol stack sends the received response message to Modbus application container. This is step inside Modbus application container.

Key in JSON message	Definition
usec	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which Modbus application container prepares a message to publish on ZMQ. This field is a part of data-model. It is repeated here for completeness.
tsMsgRcvdForProcessing	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which message from ZMQ is read in MQTT-Bridge. Modbus application container sends messages like polling data and response for on-demand requests on ZMQ to MQTT-Bridge.
tsMsgReadyForPublish	This is applicable for all on-demand read/ write and polling operations. Epoch timestamp (in microseconds) at which MQTT-Bridge prepares a message to publish on MQTT.

7.1 Data Polling

In datapoint YML configuration file, a polling frequency is configured. As per polling frequency, data is fetched from end point and published on MQTT by UWC container. This section describes how to read data for polled points using MQTT.

The data actions which are “Polling” actions are initiated by the Protocol container (in this case the Modbus protocol application (i.e. the driver) within the Modbus container.

To receive polled data: Application should use a topic in following format to receive (i.e., subscribe) polling data from MQTT:

MQTT topic to receive (i.e., subscribe) write response: /device/wellhead/point/update

Please refer table in section 6 for details of fields.

Example:

Polling Topic: /flowmeter/PL0/D3/update

Polling Message: Success Response

```
{
    "driver_seq":     "1153204567290051305",
    "timestamp":     "2020-05-01T06:40:25",
    "version":    "2.0",
    "realtime":   "1",
    "data_topic":     /flowmeter/PL0/D3/update",
    "wellhead":  "PL0",
    "metric":     "D3",
    "tsPollingTime":"1588315225331550",
    "reqRcvdInStack":    "1588315225331890",
    "reqSentByStack":   "1588315225333180",
    "respRcvdByStack": "1588315225333900",
    "respPostedByStack":    "1588315225333950",
    "status":      "Good",
    "value": "0x01",
    “datatype”:”boolean”
    "scaledValue":   true,
    "usec":  "1588315225334040",
    "tsMsgRcvdForProcessing":  "1588315225335060",
    "tsMsgReadyForPublish":     "1588315225335420"
}
```


Polling Message: Error Response


```
{
    "driver_seq":     "1153204567290051305",
    "timestamp":     "2020-05-01T06:40:25",
    "version":    "2.0",
    "realtime":   "1",
    "data_topic":     /flowmeter/PL0/D3/update",
    "wellhead":  "PL0",
    "metric":     "D3",
    "tsPollingTime":"1588315225331550",
    "reqRcvdInStack":    "1588315225331890",
    "reqSentByStack":   "1588315225333180",
    "respRcvdByStack": "0",
    "respPostedByStack":    "1588315225333950",
    "status" : "Bad",
    "error_code" : "2003",
    "lastGoodUsec" : "1588315225333897",
    "value" : "0x01",
    “datatype”:”boolean”
    "scaledValue":   true,
    "usec" : "1588315225334040",
    "tsMsgRcvdForProcessing" : "1588315225335060",
    "tsMsgReadyForPublish" : "1588315225335420"
}
```

7.2 On-Demand Write

This section describes how to write data to some specific Modbus point using MQTT.

To send request: Application should use a topic in following format to send (i.e. publish) write request on MQTT:

MQTT topic to send (i.e., publish) write request: /device/wellhead/point/write

To receive response: Application should use a topic in following format to receive (i.e. subscribe) response of write request from MQTT:

MQTT topic to receive (i.e., subscribe) write response: /device/wellhead/point/writeResponse

Please refer table in section 6 for details of fields.

Example:

Request Topic: /flowmeter/PL0/Flow/write

Request Message:

{"wellhead":"PL0","command":"Flow","value":"0x00","timestamp":"2019-09-20 12:34:56","usec":"1571887474111145","version":"2.0","app_seq":"1234"}

A message without “realtime” field is treated as a non-realtime message. To execute a message in realtime way, a field called “realtime” should be added as shown below:

{"wellhead":"PL0","command":"Flow","value":"0x00","timestamp":"2019-09-20 12:34:56","usec":"1571887474111145","version":"2.0","app_seq":"1234","realtime":"1"}

A message with “value” is treated as On-Demand Write from vendor App.

{"wellhead" : "PL0","command" : "INT16_MF10","timestamp" : "2019-09-20 12:34:56",
"usec" : "1571887474111145","version" : "2.0","realtime" : "0","app_seq" : "1234", "scaledValue" : 12}

A message with “scaledValue” is treated as On-Demand Write from Ignition system.

The “value” / "scaledValue" field represents value to be written to end device as a part of on-demand write operation.

Response Topic: /flowmeter/PL0/Flow/writeResponse

Response Message: Success Response

{

```
        "app_seq":   "1234",
        "version":   "2.0",
        "realtime":   "0",
        "data_topic":   "/flowmeter/PL0/Time0/writeResponse",
        "wellhead":   "PL0",
        "metric":   "Time0",
        "tsMsgRcvdFromMQTT":   "1585660044014345",
        "tsMsgPublishOnEII:   "1585660044017877",
        "reqRcvdByApp":   "1585660044021380",
        "reqRcvdInStack":   "1585660044023582",
        "reqSentByStack":   "1585660044025671",
        "respRcvdByStack":   "1585660044025636",
        "respPostedByStack":   "1585660044025712",
        "status":   "Good",
        "usec":   "1585660044026131",
        "tsMsgRcvdForProcessing":   "1585660044027184",
        "tsMsgReadyForPublish":   "1585660045024371"
    }
```


Response Message: Error Response


```
{
        "app_seq" : "1234",
        "timestamp" : "2020-04-24 06:10:30",
        "version" : "2.0",
        "realtime" : "1",
        "data_topic" : "/flowmeter/PL0/Flow/writeResponse",
        "wellhead" : "PL0",
        "metric" : "Flow",
        "tsMsgRcvdFromMQTT" : "1587708630464551",
        "tsMsgPublishOnEII : "1587708630465375",
        "reqRcvdByApp" : "1587708630465988",
        "reqRcvdInStack" : "1587708630466345",
        "reqSentByStack" : "0",
        "respRcvdByStack" : "0",
        "respPostedByStack" : "1587708630466627",
        "status" : "Bad",
        "error_code" : "2003",
        "usec" : "1587708630466935",
        "tsMsgRcvdForProcessing" : "1587708630467797",
        "tsMsgReadyForPublish" : "1587708630468239"
    }
```

Response Message: Error Response for Invalid request JSON

{
"app_seq":"1234",
"timestamp":"2020-05-13 06:43:50",
"version":"2.0",
"realtime":"0",
"topic":"/iou/PL0/D1/writeResponse",
"wellhead":"PL0",
"metric":"D1",
"tsMsgRcvdFromMQTT":"1589352230212884",
"tsMsgPublishOnEII":"1589352230214516",
"reqRcvdByApp":"1589352230215485",
"reqRcvdInStack":"0",
"reqSentByStack":"0",
"respRcvdByStack":"0",
"respPostedByStack":"0",
"status":"Bad",
"usec":"1589352230217118",
"error_code":"102",
"tsMsgRcvdForProcessing":"1589352230220450",
"tsMsgReadyForPublish":"1589352230220503"
}

7.3 On-Demand Read

This section describes how to read data from some specific Modbus point using MQTT.

To send request: Application should use a topic in following format to send (i.e., publish) read request on MQTT:

MQTT topic to send (i.e. publish) read request: /device/wellhead/point/read

To receive response: Application should use a topic in following format to receive (i.e., subscribe) response of read request from MQTT:

MQTT topic to receive (i.e., subscribe) write response: /device/wellhead/point/readResponse

Please refer table in section 6 for details of fields.

Example:

Request Topic: /flowmeter/PL0/Flow/read

Request Message:

{"wellhead":"PL0","command":"Flow","timestamp":"2019-09-20 12:34:56","usec":"1571887474111145","version":"2.0","app_seq":"1234"}

A message without “realtime” field is treated as a non-realtime message. To execute a message in realtime way, a field called “realtime” should be added as shown below:

{"wellhead":"PL0","command":"Flow","timestamp":"2019-09-20 12:34:56","usec":"1571887474111145","version":"2.0","app_seq":"1234",”realtime”:” 1”}

Response Topic: /flowmeter/PL0/Flow/readResponse

Response Message: Success Response

{
"app_seq":"1234",
"timestamp":"2020-04-24 05:24:02",
"version":"2.0",
"realtime":"0",
"data_topic":"/flowmeter/PL0/Flow/readResponse",
"wellhead":"PL0",
"metric":"Flow",
"tsMsgRcvdFromMQTT":"1587705842296135",
"tsMsgPublishOnEII":"1587705842296550",
"reqRcvdInStack":"1587705842296921",
"reqSentByStack":"1587705842298063",
"reqRcvdByApp":"1587705842296836",
"respRcvdByStack":"1587705842298666",
"respPostedByStack":"1587705842298686",
"status":"Good",
"value":"0x01",
“datatype”:”boolean”
"scaledValue": true,
"usec":"1587705842298811",
"tsMsgRcvdForProcessing":"1587705842299038",
"tsMsgReadyForPublish":"1587705842299115"
}

Response Message: Error Response

{
"app_seq" : "1234",
"timestamp" : "2020-04-24 06:17:33",
"version" : "2.0",
"realtime" : "0",
"data_topic" : "/flowmeter/PL0/Flow/readResponse",
"wellhead" : "PL0",
"metric" : "Flow",
"tsMsgRcvdFromMQTT" : "1587709053533410",
"tsMsgPublishOnEII" : "1587709053534618",
"reqRcvdInStack" : "1587709053535694",

"reqRcvdByApp" : "1587709053535467",
"reqSentByStack" : "0",
"respRcvdByStack" : "0",
"respPostedByStack" : "1587709053536172",
"status" : "Bad",
"value" : "",
“datatype”:”boolean”
"scaledValue":,
"error_code" : "2003",
"usec" : "1587709053536590",
"tsMsgRcvdForProcessing" : "1587709053537377",
"tsMsgReadyForPublish" : "1587709053537647"
}

Response Message: Error Response for Invalid Input JSON

{
"app_seq" : "1234",
"timestamp" : "2020-04-24 06:22:42",
"version" : "2.0",
"realtime" : "0",
"data_topic" : "/flowmeter/PL0/Flow/readResponse",
"wellhead" : "PL0",
"metric" : "Flow1",
"tsMsgRcvdFromMQTT" : "1587709362173590",
"tsMsgPublishOnEII" : "1587709362173872",
"reqRcvdInStack" : "0",
"reqSentByStack" : "0",
"reqRcvdByApp" : "1587709362174221",
"respRcvdByStack" : "0",
"respPostedByStack" : "0",
"status" : "Bad",
"value" : "",
“datatype”:”boolean”
"scaledValue": ,
"error_code" : "102",
"usec" : "1587709362174333",
"tsMsgRcvdForProcessing" : "1587709362174590",
"tsMsgReadyForPublish" : "1587709362174647"

}

7.4 KPI Application

Following data (if available) is logged in a log-file by KPI Application for control loops.

UWC Modbus Operations

Field	Description
pollSeq	Driver sequence number received in polling
pollTopic	Topic received for polling
pollStatus	Status received for polling
pollValue	Value received in polling
pollError	Error code received for polling
tsPollingTime	Timestamp when polling time is triggered
pollReqRcvdInStack	Timestamp when polling read request is received in stack
pollReqSentByStack	Timestamp when polling read request is sent by stack
pollRespRcvdByStack	Timestamp when polling read response is received in stack from device
pollRespPostedByStack	Timestamp when polling read response is posted to Modbus container by stack
pollRespPostedToEII	Timestamp when polling is posted to ZMQ by Modbus container
pollDataRcvdInExport	Timestamp when polling data is received in MQTT-Bridge (applicable only when KPI App is executed in MQTT mode)
pollDataPostedToMQTT	Timestamp when polling data is posted to MQTT by MQTT-Bridge (applicable only when KPI App is executed in MQTT mode)
pollDataRcvdInApp	Timestamp when polling data is received in KPI Application
appSeq	App sequence number used for the write operation
wrRspTopic	Topic received for write response
wrRspStatus	Status received for write response
wrRspError	Error code received for write response. It represents the value received from Modbus container. Additionally, following 2 dummy error codes are set to handle error conditions within KPI App: • WrReqInitFailed/writeResponse: It means the write request could not be initiated.

Field	Description
	• WrRespNotRcvd/writeResponse: It means the write response of last sent request is not received.
wrReqCreation	Timestamp when KPI App creates a write request
wrReqRcvdInExport	Timestamp when write request is received in MQTT-Bridge (applicable only when KPI App is executed in MQTT mode)
wrReqPublishOnEII	If KPI App is running in MQTT mode, it represents a timestamp when the write request is published to EII by MQTT-Bridge If KPI App is running in ZMQ mode, it represents a timestamp when the write request is published to EII by KPI App
wrReqRcvdByModbus	Timestamp when write request is received in Modbus container
wrReqRcvdInStack	Timestamp when write request is received in stack
WrReqSentByStack	Timestamp when write request is sent by stack
WrRespRcvdByStack	Timestamp when write response is received in stack from device
wrRespPostedByStack	Timestamp when write response is posted to Modbus container by stack
wrRespPostedToEII	Timestamp when write response is posted to ZMQ by Modbus container
wrRespRcvdInExport	Timestamp when the write response is received in MQTT-Bridge (applicable only when KPI App is executed in MQTT mode)
wrRespPostedToMQTT	Timestamp when the write response is posted to MQTT by MQTT-Bridge (applicable only when KPI App is executed in MQTT mode)
wrRespRcvInApp	Timestamp when write response is received in application

8.0 Sparkplug-Bridge Operations

Sparkplug-Bridge implements Eclipse Foundation's SparkPlug standard.

(Ref: https://www.eclipse.org/tahu/spec/Sparkplug%20Topic%20Namespace%20and%20State%20ManagementV2.2-with%20appendix%20B%20format%20-%20Eclipse.pdf)

This section explains the features in detail. UWC gateway acts as a "node" as per SparkPlug standard. Please note that Sparkplug-Bridge is an under-development feature and hence not all message types are supported from SparkPlug.

This section also explains how information from real device and virtual device is mapped to SparkPlug formatted data.

8.1 App (virtual device) communication

Apps running on UWC platform can be represented as a SparkPlug device to SCADA Master. SCADA Master can monitor, control these apps using SparkPlug mechanism. Sparkplug-Bridge defines following to enable this communication between apps and SCADA Master:

TemplateDef message: This allows providing a definition for a Sparkplug Template i.e., UDT

BIRTH message: This corresponds to a SparkPlug DBIRTH message.

DEATH message: This corresponds to a SparkPlug DDEATH message.

DATA message: This corresponds to a SparkPlug DDATA message.

CMD message: This corresponds to a SparkPlug DCMD message.

Apps and Sparkplug-Bridge communicate over internal MQTT using above defined messages.

8.1.1 App Message Topic Format

MQTT Topic: `MESSAGETYPE/APPID/SUBCLASS`

Where,

- MESSAGETYPE: Any of "BIRTH", "DEATH", "DATA", "CMD"
- APPID: Any string e.g., "UWCP"

- SUBCLASS: Any string like wellhead-id e.g., “PL0”. This is not needed in case of DEATH message.

Sparkplug-Bridge uses following format to represent name of virtual device in SparkPlug Topic namespace:

[value of “APPID” from app message topic] + “-“ + [value of “SUBCLASS” from app message topic]

8.1.2 App Message - BIRTH

MQTT Topic: `BIRTH/APPID/SUBCLASS`

Message format:

It is a JSON format message which contains a list of metrics having following fields:

Field Name	Datatype	Description
name	String	Metric name
dataType	String	Datatype of the metric. Allowed values: • Boolean • UInt8 • UInt16 • UInt32 • UInt64 • Int8 • Int16 • Int32 • Int64 • Float • Double • String • UDT* Note: “UDT” type is explained in subsequent section.
value	As per dataType	Value of a metric as per dataType defined above
timestamp	UInt64	Time the message was transmitted. (UNIX, UTC, Milliseconds)

Example:

```
{
  "metrics": [
    {
      "name": "Properties/Version",
      "dataType": "String",
```

```
        "value": "2.0.0.1",
        "timestamp": 1486144502122
      },
      {
        "name": "Properties/RTU_Time",
        "dataType": "String",
        "value": "1234",
        "timestamp": 1486144502122
      },
      {
        "name": "UDT/Prop1",
        "dataType": "UDT",
        "value": {
          "udt_ref": {
            "name": "custom_udt",
            "version": "1.0"
          },
          "metrics": [
            {
              "name": "M1",
              "dataType": "String",
              "value": "2.0.0.1",
              "timestamp": 1486144502122
            },
            {
              "name": "RTU_Time",
              "dataType": "Int32",
              "value": 1234,
              "timestamp": 1486144502122
            }
          ],
          "parameters": [
            {
              "name": "P1",
              "dataType": "String",
              "value": "P1Val"
            },
            {
              "name": "P2",
              "dataType": "Int32",
              "value": 100
            }
          ]
        }
      }
    ]
  }
```

Data Flow:

This message is published by App over MQTT broker and subscribed by Sparkplug-Bridge. This message provides information about all metrics related to a SUBCLASS which App wants to expose to a SCADA Master.

Sparkplug-Bridge publishes a DBIRTH message to SCADA Master if metrics contain a new metric or if datatype of any of metrics is changed.

Notes:

- If the App publishes multiple BIRTH messages for a SUBCLASS, then Sparkplug-Bridge remembers all metrics reported in all BIRTH messages. Sparkplug-Bridge reports all these metrics to SCADA Master in DBIRTH message. This data with Sparkplug-Bridge is cleared on restart of gateway or Sparkplug-Bridge container.
- A DBIRTH message can result in refreshing of data in Sparkplug-Bridge and in SCADA Master. Hence, it is recommended for an App to provide information about all metrics in one BIRTH message. App should avoid using multiple BIRTH messages for same SUBCLASS.
- If App wants to publish a metric of type "UDT", the definition of "UDT" should be provided prior to publishing the BIRTH message. UDT definition can be provided using "TemplateDef" message, explained in subsequent section.

  Following information is required as a part of "value" key when UDT type is used:

Field Name	Datatype	Description
udt_ref	Collection of fields	It consists of following fields: • name: String type • version: String type Above fields indicate the UDT definition used (i.e., adhered) by this UDT metric.
metrics	Array of metrics	Each metric consists of following fields: • name: String type • dataType: String type • value: As per dataType • timestamp: UInt64 For details, refer UDT definition message.
parameters	Array of metrics	Each parameter consists of following fields: • name: String type • dataType: String type • value: As per dataType For details, refer UDT definition message.

8.1.3 App Message - DATA

MQTT Topic: `DATA/APPID/SUBCLASS`

Message format:

It is a JSON format message which contains a list of metrics having following fields:

Field Name	Datatype	Description
name	String	Metric name
dataType	String	Datatype of the metric. Allowed values: • Boolean • UInt8 • UInt16 • UInt32 • UInt64 • Int8 • Int16 • Int32 • Int64 • Float • Double • String • UDT* Note: "UDT" type is explained in subsequent section.
value	As per dataType	Value of a metric as per dataType defined above
timestamp	UInt64	Time the message was transmitted. (UNIX, UTC, Milliseconds). This is an optional field. If not provided, then system will assign a timestamp while publishing a corresponding SparkPlug message to SCADA Master. If this value is present, then it will be used in SparkPlug message.

Example:

```
{
  "metrics": [
    {
      "name": "Properties/Version",
      "dataType": "String",
      "value": "5.0.0.1",
      "timestamp": 1486144502122
```

```
    },
    {
      "name": "UDT/Prop1",
      "dataType": "UDT",
      "value": {
        "metrics": [
          {
            "name": "M1",
            "dataType": "String",
            "value": "a.b",
            "timestamp": 1486144502122
          }
        ]
      }
    }
  ]
}
```

Data Flow:

This message is published by App over MQTT broker and subscribed by Sparkplug-Bridge. This message provides information about all changed metrics related to a SUBCLASS.

Sparkplug-Bridge publishes a DDATA message to SCADA Master if value of any of "known metrics" is changed compared to last known value from a BIRTH or DATA message.

Note: A "known metric" is one which was reported in BIRTH message. The name and datatype for a "known metric" in DATA message and BIRTH message shall match.

8.1.4 App Message - CMD

MQTT Topic: `CMD/APPID/SUBCLASS`

Message format:

It is a JSON format message which contains a list of metrics having following fields:

Field Name	Datatype	Description
name	String	Metric name
dataType	String	Datatype of the metric. Allowed values: • Boolean • UInt8 • UInt16 • UInt32 • UInt64 • Int8

		• Int16 • Int32 • Int64 • Float • Double • String • UDT* Note: "UDT" type is explained in subsequent section.
value	As per dataType	Value of a metric as per dataType defined above
timestamp	UInt64	Time the message was transmitted. (UNIX, UTC, Milliseconds). This is an optional field. If not provided, then system will assign a timestamp while publishing a corresponding SparkPlug message to SCADA Master. If this value is present, then it will be used in SparkPlug message.

Example:

```
{
  "metrics": [
    {
      "name": "Properties/Version",
      "dataType": "String",
      "value": "7.0.0.1",
      "timestamp": 1486144502122
    },
    {
      "name": "UDT/Prop1",
      "dataType": "UDT",
      "metrics": [
        {
          "dataType": "Int32",
          "value": 4,
          "name": "RTU_Time",
          "timestamp": 1614512107195
        }
      ],
      "timestamp": 1614512107195
    }
  ]
}
```

Data Flow:

This message is published by Sparkplug-Bridge over MQTT broker and subscribed by App. This message provides information about control command i.e., DCMD received from SCADA Master.

Sparkplug-Bridge publishes a CMD message to the App if DCMD message is received for a known metric.

Note: A “known metric” is one which was reported in BIRTH message. The name and datatype for a “known metric” in DCMD message and BIRTH message shall match.

8.1.5 App Message - DEATH

MQTT Topic: `DEATH/APPID`

Message format:

It is a JSON format message which contains following fields:

Field Name	Datatype	Description
timestamp	UInt64	Time the message was transmitted. (UNIX, UTC, Milliseconds). This is an optional field. If not provided, then system will assign a timestamp while publishing a corresponding SparkPlug message to SCADA Master. If this value is present, then it will be used in SparkPlug message.

Example:

```
{
  "timestamp": 1486144502122
}
```

Data Flow:

When App's connection with MQTT broker breaks then this message is published.

Sparkplug-Bridge publishes a DDEATH message to SCADA Master for all known SUBCLASS associated with the App.

8.1.6 App Message - TemplateDef

MQTT Topic: `TemplateDef`

Message format:

It is a JSON format message which contains a list of metrics having following fields:

Field Name	Datatype	Description
udt_name	String	Name of Sparkplug Template i.e., UDT
version	String	UDT definition version
metrics	List of metrics	A UDT consists of nested metrics. This field defines the metrics which are a part of UDT. Each metric contains following fields: • name • dataType

		• value These fields are explained in following rows.
Keys within each “metric”		
name	String	Name of metric inside UDT definition
dataType	String	Datatype of the metric. Allowed values: • Boolean • UInt8 • UInt16 • UInt32 • UInt64 • Int8 • Int16 • Int32 • Int64 • Float • Double • String • UDT
value	As per dataType	Value of a metric as per dataType defined above
parameters	List of parameters	Each parameter contains following fields: • name • dataType • value These fields are like the metric fields, explained earlier. Parameters are provided for an App in DBIRTH message.

Example:

```
{
  "udt_name": "custom_udt",
  "version": "1.0",
  "metrics": [
    {
      "name": "M1",
      "dataType": "String",
      "value": ""
    },
    {
      "name": "RTU_Time",
      "dataType": "Int32",
```

```
        "value": 0
      }
    ],
    "parameters": [
      {
        "name": "P1",
        "dataType": "String",
        "value": ""
      },
      {
        "name": "P2",
        "dataType": "Int32",
        "value": 0
      }
    ]
  }
```

Data Flow:

App should use this message to provide definition of a Sparkplug Template i.e., UDT. UDT definitions are published as a part of NBIRTH message. Hence, after receiving a UDT definition, Sparkplug-Bridge publishes NDEATH and then NBIRTH to SCADA-Master.

8.1.7 START_BIRTH_PROCESS

MQTT Topic: `START_BIRTH_PROCESS`

Message format:

It is an empty JSON format message:

Field Name	Datatype	Description

Example:

```
{

}
```

Data Flow:

This message is published by Sparkplug-Bridge over MQTT broker and subscribed by App. This message tells the App to publish following:

- Definition of Sparkplug Templates i.e., UDT which are used by App in BIRTH message
- BIRTH messages for all SUBCLASS the App is having. The App shall publish BIRTH messages on receiving START_BIRTH_PROCESS message.

START_BIRTH_PROCESS message will be sent on restart of Sparkplug-Bridge container or whenever Sparkplug-Bridge container needs to refresh the data that it maintains for virtual devices.

8.2 Modbus (real) device communication

Modbus devices present in network are reported to SCADA Master using SparkPlug mechanism.

Apps and Sparkplug-Bridge communicate over internal MQTT using above defined messages.

8.2.1 Support for DBIRTH

Data from device YML configuration files is used to form a DBIRTH message for real devices at the start of Sparkplug-Bridge container. One datapoint YML file corresponds to one SparkPlug template definition. One real Modbus device contains one metric of type SparkPlug template. The SparkPlug template in turn contains all other metrics which correspond to datapoints mentioned in datapoints-YML file.

8.2.2 Support for DDATA

Data from polling operation published by MQTT-Bridge over internal MQTT is used to determine a change in value of any of metrics associated with a real device. If a change is detected, a DDATA message is published by Sparkplug-Bridge.

8.2.3 Support for DCMD

When a DCMD message is received from a SCADA Master for a real device for a “known metric”, then an on-demand write operation is initiated by SCADA and sent to MQTT-Bridge over internal MQTT.

Notes:

- A “known metric” is one which is present in device YML configuration file. The name and datatype for a “known metric” in DCMD message and YML file shall match.
- A DCMD message can result in multiple on-demand write operations.

8.2.4 Support for DDEATH

Data from polling operation published by MQTT-Bridge over internal MQTT is used to determine whether a device is reachable or not, based on error_code. If device unreachable error-code is found, a DDEATH message is published by Sparkplug-Bridge. When correct values are found, a DBIRTH message is published.

8.3 SparkPlug Messages

Refer SparkPlug standard for more information.

8.3.1 NBIRTH Message

NBIRTH is Node-Birth.

On start-up, Sparkplug-Bridge module publishes this message over MQTT broker. The message is published in SparkPlug encoded format.

For Modbus real device, one datapoint YML file corresponds to one SparkPlug template. These template definitions are sent in NBIRTH message. DBIRTH message for Modbus device specifies a particular SparkPlug template.

Following are sample contents in simplified JSON format:

Topic: `spBv1.0/UWC nodes/NBIRTH/RBOX510-00`

Message:

```
{
  "timestamp": 1608243262157,
  "metrics": [
    {
      "name": "Name",
      "timestamp": 1608243262157,
      "dataType": "String",
      "value": "SPARKPLUG-BRIDGE”
    },
    {
      "name": "bdSeq",
      "timestamp": 1608243262157,
      "dataType": "UInt64",
      "value": 0
    },
   {
      "name": "Node Control/Rebirth",
      "timestamp": 1608243262157,
      "dataType": "Boolean",
      "value": false
    },
    {
      "name": "iou_datapoints",
      "timestamp": 1608243262157,
      "dataType": "Template",
      "value": {
        "version": "1.0.0",
        "reference": "",
        "isDefinition": true,
        "metrics": [
          {
```

```
            "name": "D1",
            "timestamp": 1608243262157,
            "dataType": "String",
            "properties": {
              "Pollinterval": {
                "type": "UInt32",
                "value": 0
              },
              "Realtime": {
                "type": "Boolean",
                "value": false
              }
            },
            "value": ""
          },
          {
            "name": "D2",
            "timestamp": 1608243262157,
            "dataType": "String",
            "properties": {
              "Pollinterval": {
                "type": "UInt32",
                "value": 0
              },
              "Realtime": {
                "type": "Boolean",
                "value": false
              }
            },
            "value": ""
          }
        ],
        "parameters": [
          {
            "name": "Protocol",
            "type": "String",
            "value": ""
          }
        ]
      }
    }
  ],
  "seq": 0,
  "uuid": "SPARKPLUG-BRIDGE"
}
```


8.3.2 NDEATH Message

NDEATH is Node-Death.

Whenever Sparkplug-Bridge module's connection with MQTT broker breaks, the MQTT broker publishes this message. The message is published in text format.

Following are sample contents in simplified JSON format:

Topic: `spBv1.0/UWC nodes/NDEATH/RBOX510-00`

Message:

```
{
  "timestamp": 1592306298537,
  "metrics": [
    {
      "name": "bdSeq",
      "alias": 10,
      "timestamp": 1592306298537,
      "dataType": "UInt64",
      "value": 0
    }
  ],
  "seq": 0
}
```

8.3.3 DBIRTH Message

DBIRTH is Device-Birth.

On start-up, Sparkplug-Bridge module publishes this message over MQTT broker. The message is published in SparkPlug encoded format.

Following are sample contents in simplified JSON format for a Modbus device:

```
{
  "timestamp": 1608242600219,
  "metrics": [
    {
      "name": "iou",
      "timestamp": 1608242600219,
      "dataType": "Template",
      "value": {
        "version": "1.0.0",
        "reference": "iou_datapoints",
        "isDefinition": false,
        "metrics": [
          {
            "name": "D1",
            "timestamp": 1608242599889,
            "dataType": "Int16",
            "properties": {
               "Scale": {
               "type": "Double",
               "value": 1
               },
              "Pollinterval": {
                "type": "UInt32",
                "value": 1000
```

```
                    },
                    "Realtime": {
                      "type": "Boolean",
                      "value": false
                    }
                  },
                  "value": 0
                },
                {
                  "name": "D2",
                  "timestamp": 1608242599889,
                  "dataType": "Int32",
                  "properties": {
                     "Scale": {
                     "type": "Double",
                     "value": 1
                     },
                    "Pollinterval": {
                      "type": "UInt32",
                      "value": 1000
                    },
                    "Realtime": {
                      "type": "Boolean",
                      "value": false
                    }
                  },
                  "value": 0
                }
              ],
              "parameters": [
                {
                  "name": "Protocol",
                  "type": "String",
                  "value": "Modbus TCP"
                }
              ]
            }
          }
        ],
        "seq": 1
    }
```


8.3.4 DDEATH Message

DDEATH is Device-Death.

Sparkplug-Bridge module publishes this message over MQTT broker whenever it detects that device is not reachable. The message is published in SparkPlug encoded format.

Following are sample contents in simplified JSON format:


```
{
   "timestamp":1599467927490,
```

```
   "metrics":[],
   "seq":7
}
```

8.3.5 DDATA Message

DDATA is Device-Data.

Sparkplug-Bridge module publishes this message over MQTT broker whenever it detects a change in value of any of metrics of devices. The message is published in SparkPlug encoded format.

Following are sample contents in simplified JSON format for a Modbus device:


```
{
  "timestamp": 1608242631070,
  "metrics": [
    {
      "name": "iou",
      "timestamp": 1608242631070,
      "dataType": "Template",
      "value": {
        "version": "1.0.0",
        "reference": "iou_datapoints",
        "isDefinition": false,
        "metrics": [
          {
            "name": "D1",
            "timestamp": 1571887474111145,
            "dataType": "String",
            "value": "0x00"
          }
        ]
      }
    }
  ],
  "seq": 2
}
```


Following is sample contents in simplified JSON format for a Modbus device with scalefactor applied:


```
{
  "timestamp": 1621951388659,
  "metrics": [
    {
      "name": "flowmeter",
      "timestamp": 1621951388659,
      "dataType": "Template",
      "value": {
        "version": "1.0.0",
        "reference": "flowmeter_datapoints",
        "isDefinition": false,
        "metrics": [
          {
            "name": "D1",
            "timestamp": 1621951388658,
            "dataType": "Int32",
            "value": 2910
```

```
            }
          ]
        }
      }
    ],
    "seq": 2
}
```

8.3.6 NCMD Message

NCMD is Node-Command.

SCADA Master can tell edge node to reinitiate the node birth process. The node starts publishing NBIRTH, DBIRTH messages after receiving NCMD.

Following are sample contents in simplified JSON format:

Topic: `spBv1.0/UWC nodes/NCMD/RBOX510-00`

Message:

```
{
  "timestamp": 1615619351980,
  "metrics": [
    {
      "name": "Node Control/Rebirth",
      "timestamp": 1615619351980,
      "dataType": "Boolean",
      "value": true
    }
  ],
  "seq": -1
}
```

9.0 Debugging steps

Checking logs

1. Syntax - `sudo docker logs <container_name>`

e.g.:- To check modbus-tcp-container logs execute "`sudo docker logs modbus-tcp-container`" command.

2. Command to check logs inside the container "`sudo docker exec -it <container_name> bash`" and go to the "logs" directory using "`cd logs`".

3. Use "`cat <log_file_name>`" to see log file inside the container

4. Copying logs from container to host machine

Syntax - `docker cp <container_name>:<file to copy from container> <file to be copied i.e. host directory>`

5. To check the IP address of machine, use "`ifconfig`" command.

6. For Modbus RTU, to check attached COM port for serial communication, use "`dmesg | grep tty`" command.

Redirect docker logs to file including errors

```
docker logs modbus-tcp-container > docker.log 2>&1
```

Accessing container logs through docker volumes:

Go to docker volume directory using

```
cd /opt/intel/eii/container_logs/<container_name>
```

```
Where <container name> is directory name for each container (i.e. "modbus-tcp-master", "modbus-rtu-master", "mqtt-bridge", etc).
```

Example to access container logs for modbus-tcp-master container,

```
cd /opt/intel/eii/container_logs/modbus-tcp-master
```

```
cat Modbus_App.log
```

Please note: These logs are persisted across container/gateway restart.

Steps to apply new configuration (i.e. YML files)

Once YML files/docker-compose.yml are changed/Modified in `/opt/intel/eii/uwc_data` directory then, execute following command to apply new configurations,

```
sudo ./05_applyConfigChanges.sh
```

How to bring up/down UWC containers

`docker-compose down` - bring down all containers

`docker-compose up` - bring up all containers

10.0 Error Codes

MODBUS_EXCEPTION Codes

Response JSON message from Modbus container contains a code in case of error scenario.

Format: “error_code”: “number”

There are 3 classes of error codes. This section lists down the error codes:

Error Code	Description
Modbus Application Error Codes	
0	APP_SUCCESS
100	APP_ERROR_DUMMY_RESPONSE
101	APP_ERROR_REQUEST_SEND_FAILED
102	APP_ERROR_INVALID_INPUT_JSON
103	APP_ERROR_CUTOFF_TIME_INTERVAL
106	APP_JSON_PARSING_EXCEPTION
107	APP_ERROR_UNKNOWN_SERVICE_REQUEST
108	APP_ERROR_POINT_IS_NOT_WRITABLE
Modbus Protocol Standard Error Codes (Returned by slave devices)	
1001	ILLEGAL FUNCTION
1002	ILLEGAL DATA ADDRESS
1003	ILLEGAL DATA VALUE
1010	GATEWAY PATH UNAVAILABLE
Modbus Protocol Stack Error Codes	
2001	STACK_TXNID_OR_UNITID_MISSMATCH
2002	STACK_ERROR_SOCKET_FAILED
2003	STACK_ERROR_CONNECT_FAILED
2004	STACK_ERROR_SEND_FAILED
2005	STACK_ERROR_RECV_FAILED
2006	STACK_ERROR_RECV_TIMEOUT
2007	STACK_ERROR_MALLOC_FAILED
2008	STACK_ERROR_QUEUE_SEND
2009	STACK_ERROR_QUEUE_RECIVE

Error Code	Description
2010	STACK_ERROR_THREAD_CREATE
2011	STACK_ERROR_INVALID_INPUT_PARAMETER
2012	STACK_ERROR_PACKET_LENGTH_EXCEEDED
2013	STACK_ERROR_SOCKET_LISTEN_FAILED
2014	STACK_ERROR_MAX_REQ_SENT
2015	STACK_ERROR_FAILED_Q_SENT_REQ
2016	STACK_INIT_FAILED
2017	STACK_ERROR_QUEUE_CREATE
2018	STACK_ERROR_MUTEX_CREATE
2019	STACK_ERROR_STACK_IS_NOT_INITIALIZED
2020	STACK_ERROR_STACK_IS_ALREADY_INITIALIZED
2021	STACK_ERROR_SERIAL_PORT_ERROR

11.0 Steps to flash LFM BIOS

LFM is Low Frequency Mode. This mode is enabled on gateway for efficient power usage.

Following steps and BIOS are applicable for below model of Device:

RBOX510 ATEX & C1D2 ANTI-EXPLOSIVE CERTIFIED ROBOST DIN-RAIL FANLESS SYS.W/ATOM E3827(1.75GHz)

	LFM (500)	LFM_1750	Original
Axiomtek ICO-300	87842XV.102	None	87842V.105
Axiomtek RBOX510	XN.001	0502_1500M.ROM	A.103

Steps for converting to LFM

Use files from **0502_1500m.zip** folder

1. Create a FAT32 file-system on a USB stick, then dump each BIOS file structure to the root as needed.
2. Prepare the LFM BIOS first on USB, then boot to the USB's EFI device (boot priorities).
3. After setting the Boot priorities save & exit from boot menu. You will be switched to Command window. Press any key to enter to command line, type `flash.nsh` to update the BIOS.
4. Restart the HW and you will now be locked at 1750MHz.
5. Check frequency of device using command $ `cat /proc/cpuinfo | grep "MHz"`

Steps for reverting to normal Frequency

Use files from **A.103** folder

1. Create a FAT32 file-system on a USB stick, then dump each BIOS file structure to the root as needed.
2. Prepare the LFM BIOS first on USB, then boot to the USB's EFI device (boot priorities).

3. After setting the Boot priorities save & exit from boot menu. You will be switched to Command window. Press any key to enter to command line, type `flash.nsh` to update the BIOS.

4. Restart the HW and you will now be locked at 1750MHz

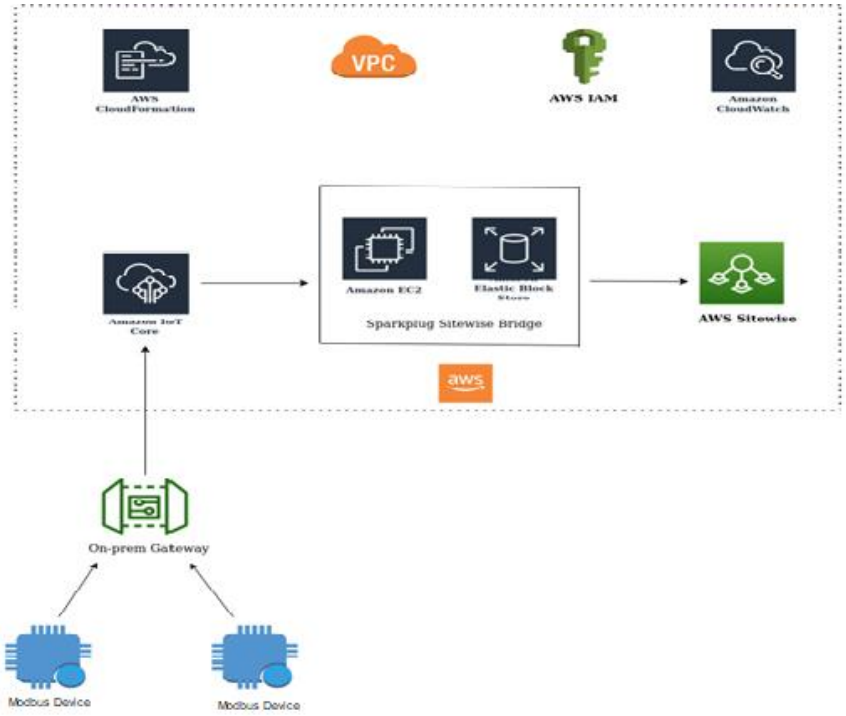
5. Check frequency of device using command $ `cat /proc/cpuinfo | grep "MHz"`

12.0 UWC Gateway to Cloud Communication

Below steps describe UWC Gateway and cloud communication architecture and steps to connect UWC Gateway to AWS Sitewise.

12.1 Architecture

Modbus devices connects to the on-prem UWC gateway. The gateway is having Sparkplug MQTT client which securely publishes Sparkplug format data to AWS IoT Core. AWS IoT Core service provisions cloud connectivity to IoT edge devices. AWS IoT Core possesses an MQTT broker as one of its components. With this connectivity, UWC gateway published data is available in the AWS cloud. Please find more information about AWS IoT Core at https://aws.amazon.com/iot-core.



Sparkplug Sitewise Bridge (SSB) is a service which rapidly connects operational technology (OT) data from Industrial Operations (on-prem data) to AWS IoT Sitewise with minimal configuration and zero coding. Please find more information on SSB at https://aws.amazon.com/marketplace/pp/Cirrus-Link-Sparkplug-SiteWise-Bridge/B08L8KNCNN.

SSB software runs in an EC2 instance which is running in AWS cloud. SSB software comprises MQTT client which subscribes to the AWS IoT Core broker to receive UWC gateway data. When SSB receives UWC gateway data it creates and update resources (Assests, Models) in AWS Sitewise. In AWS Sitewise, user can monitor UWC gateway data. Please find more information about Sitewise at https://aws.amazon.com/iot-sitewise/.

12.2 Installation and Configuration

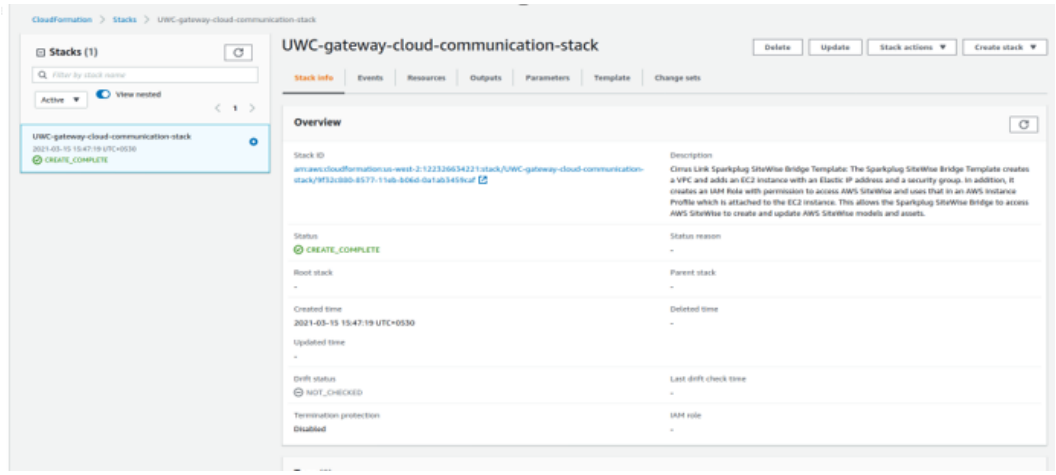
12.2.1 SSB installation and cloud infrastructure provisioning

We need to provision the AWS infrastructure and install SSB in the EC2 instance. Please use below link to carry out SSB installation and cloud infrastructure provisioning procedure -

https://docs.chariot.io/display/CLD80/IBAS%3A+Installation

Please note that there are two different delivery methods for SSB installation. Please select 'CloudFormation Template' as delivery method.

Once the process is completed, the result will be 'CREATE_COMPLETE.'



12.2.2 AWS IoT core broker and SSB configuration

A ‘thing' needs to be created in AWS IoT core which represent the IoT edge device i.e., UWC gateway. SSB needs to be configured so that it can access IoT core to fetch the UWC gateway data. Please use the link to carry out the complete AWS IoT Core broker and SSB configuration procedure - https://docs.chariot.io/display/CLD80/SSB%3A+Quickstart.

Alternate link to get an insight on the creation of a 'thing' in AWS IoT core - https://docs.aws.amazon.com/iot/latest/developerguide/iot-moisture-create-thing.html

12.2.3 UWC gateway configuration

SSL certificates which were created in STEP 2 during the creation of a ‘thing’ in AWS IoT core must be inputted while running the ‘01_pre-requisites.sh’ script.

```
$sudo ./02_provision_UWC.sh --deployMode=dev --recipe=3 --
isTLS=yes --caFile="/<path>/root-ca.crt" --crtFile="/<path>
/client.crt" --keyFile="/<path> client.key" --
brokerAddr="azeyj7bji4ghe-ats.iot.us-west-2.amazonaws.com" --
brokerPort=8883 --qos=1
```

Deploy Mode ‘dev’ or ‘Prod’.

Select Recipe as 3 to have Sparkplug Container deployed.

Make sure the ‘isTLS’ argument is set to 'yes'.

Configure the ‘caFile’ argument with the path of the CA certificate obtained from AWS IoT core.

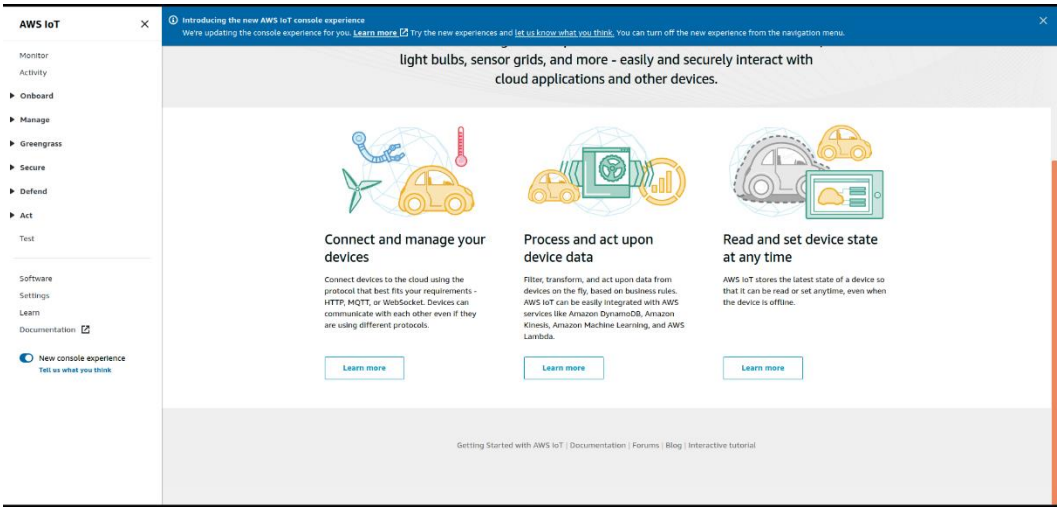
Configure the ‘crtFile’ argument with the path of the client certificate obtained from AWS IoT core.

Configure the ‘keyFile' argument with the path of the client private key obtained from AWS IoT core

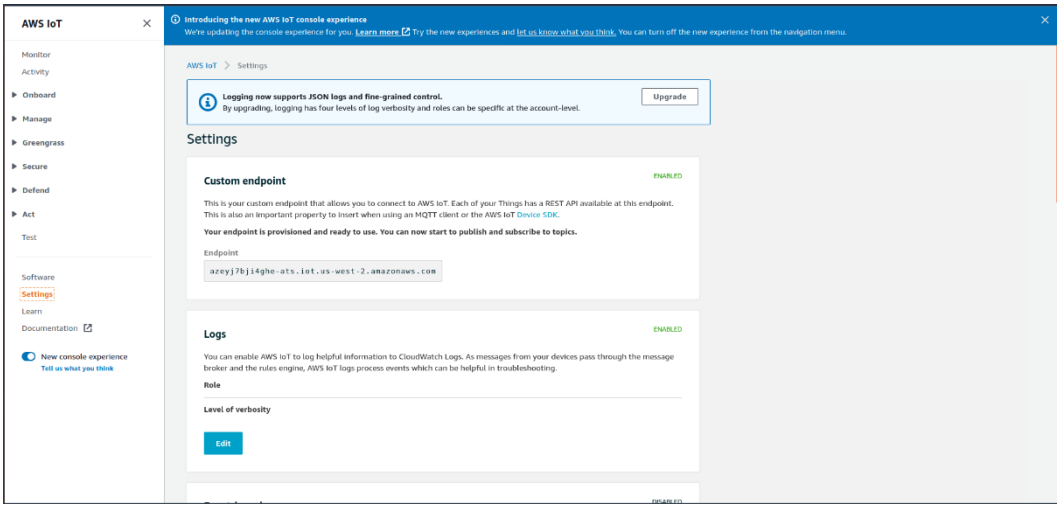
‘brokerPort’ should be set to ‘8883.’

‘brokerAddr' should be set to the custom endpoint of the AWS IoT core. Use the following couple of steps to fetch the custom endpoint.

Go to the IoT core console. Select the ‘Settings’ tab in the left pane.



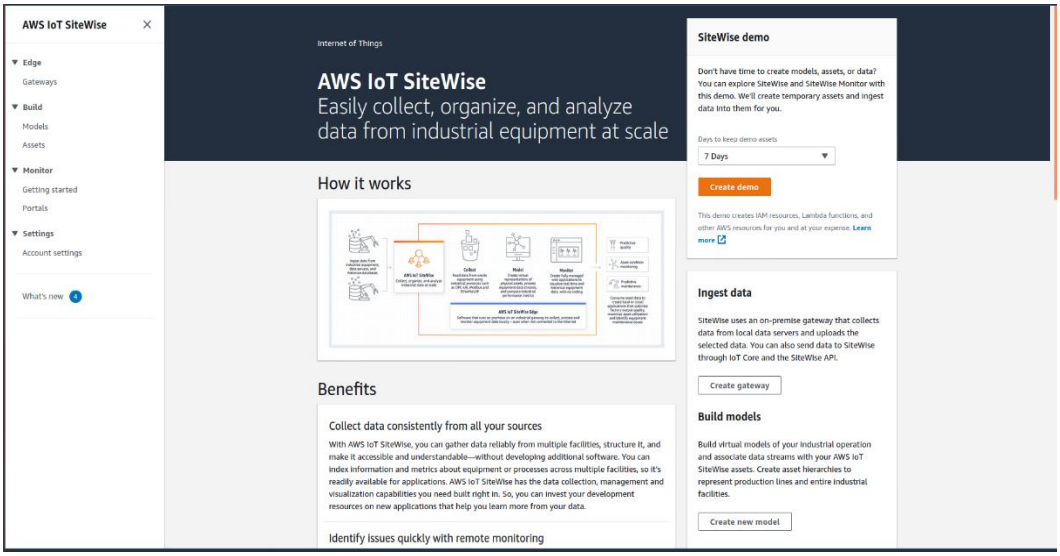
Custom endpoint which represents the IoT core broker address. This address needs to be configured in the 'brokerAddr' argument as shown in below image.



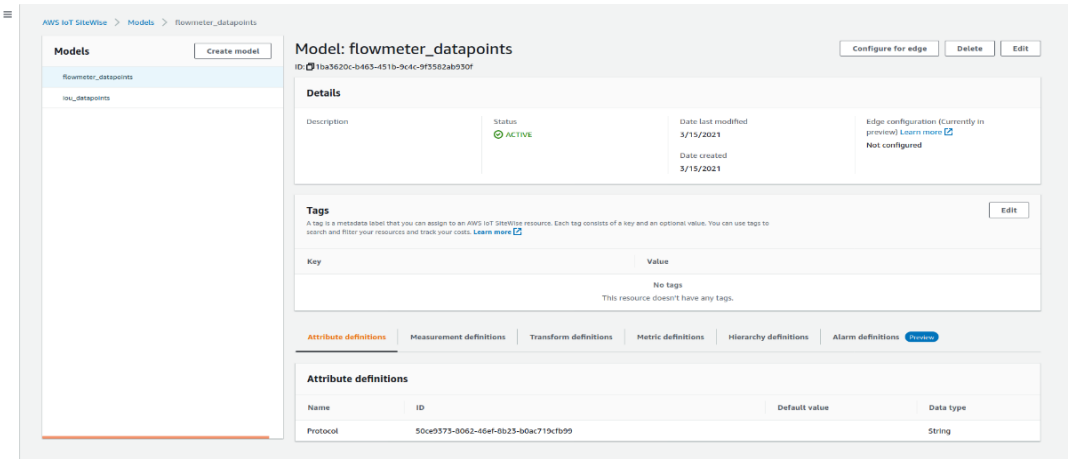
12.3 Monitor Data on Cloud

The data can be monitored on the AWS Sitewise service.

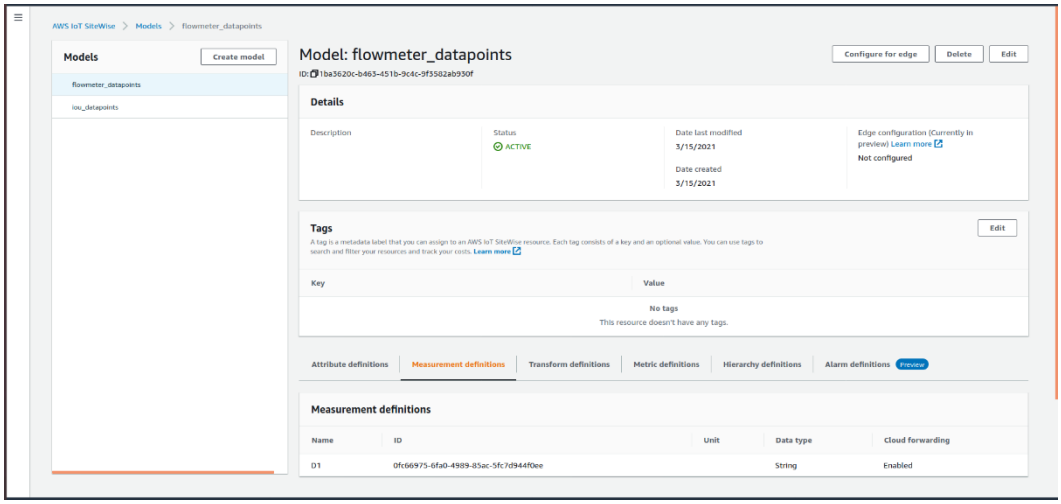
Scroll to the AWS Sitewise service in the AWS management console as shown in below image



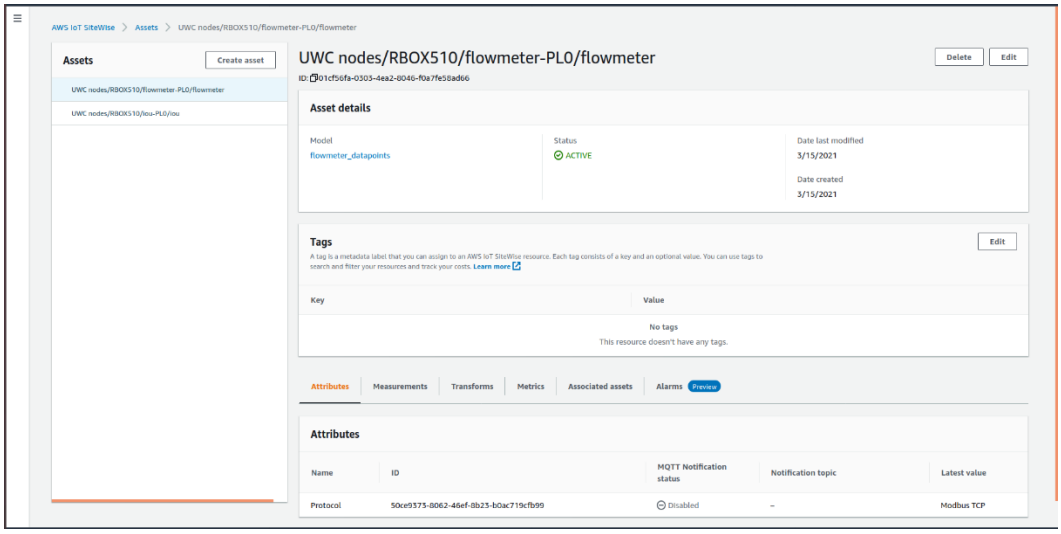
Go to the 'Models' tab. The attribute 'Protocol' of a model can be seen.



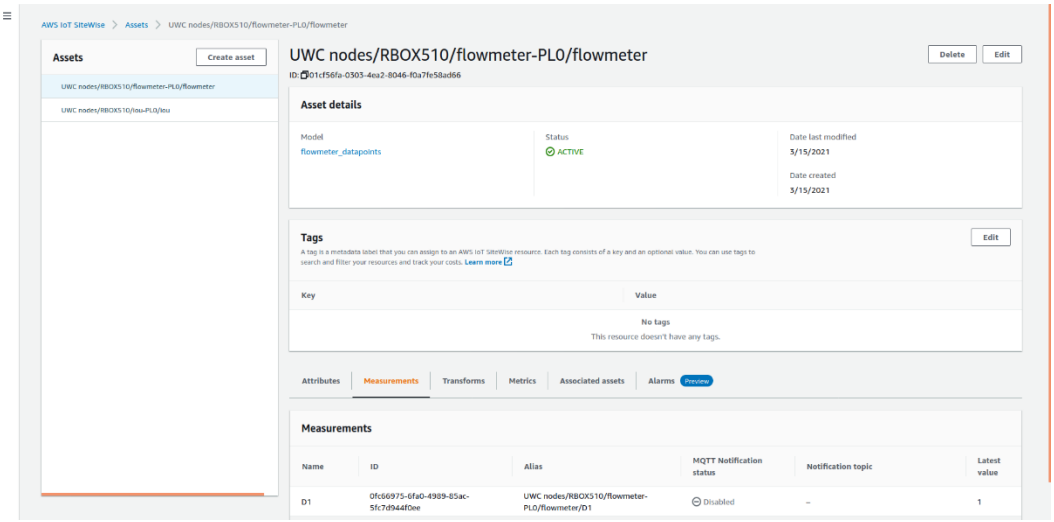
The ‘measurement' parameter representing a data point can be seen in the model.



Navigate to the ‘Assets’ tab. The attribute ‘Protocol’ can be seen with its defined value.



The ‘measurement' parameter representing a data point can be seen in the asset with its defined value.



NOTE: One should delete old Assets & Models from AWS IoT to ensure the updated Assets and Models get reflected. Duplicate Assets and Models will not be refreshed.

13.0 Steps to Apply RT Patch

13.1 Install prerequisites.

Install all the prerequisites using following command

```
sudo apt-get install -y libncurses-dev libssl-dev bison flex build-essential wget
```

Note: It will prompt to update package runtime, click on yes button.

13.2 Keyboard shortcuts for menuconfig UI

#	Task/Use	Keyboard Key
1	To select specific kernel feature	Space bar
2	To come out of current window	Esc Esc
3	To save current setting	Click on <save> button
4	Exit	Click on <exit> button

13.3 Steps to apply PREEMPT_RT patch

This section provides steps to apply PREEMPT_RT patch

Steps:

1. Make a working directory on system
   `$ mkdir ~/kernel && cd ~/kernel`

2. Download kernel in `~kernel` directory created in step 1
   - **Download kernel manually**
     Link for download - https://www.kernel.org/pub/linux/kernel/

   This will download kernel manually or use following command to download it from command line inside current directory.

   ```
   $ wget https://mirrors.edge.kernel.org/pub/linux/kernel/v4.x/linux-4.19.72.tar.gz
   ```

Recommendation: Please get Linux kernel version 4.19.72

- **Download preempt rt patch**
  Link for download - https://www.kernel.org/pub/linux/kernel/projects/rt/ this will download patch manually or use following command to download it from command line inside current directory.
  ```
  wget
  https://mirrors.edge.kernel.org/pub/linux/kernel/projects/rt/4.19/older/patch-4.19.72-rt26.patch.gz
  ```
  Recommendation: Please get PREEMPT_RT version 4.19.72-rt26

3. Unzip the kernel using following command
   ```
   $ tar -xzvf linux-4.19.72.tar.gz
   ```

4. Patch the kernel
   ```
   $ cd linux-4.19.72
   $ gzip -cd ../patch-4.19.72-rt26.patch.gz | patch -p1 --verbose
   ```
5. Launch the graphical UI for setting configurations
   The next command launches a graphical menu in the terminal to generate the .config file
   ```
   $ make menuconfig
   ```

Graphical UI is shown below:

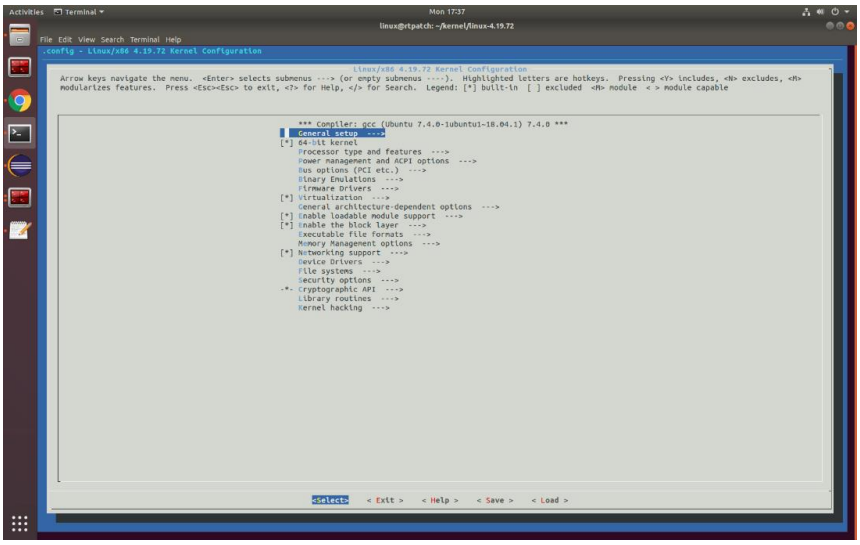


Figure 2: Main launching screen

6. Select the preemption model as Basic RT using tab key on keyboard

    1) Select and enter on “General setup” option.

    2) Select and Enter on Preemption Model (Voluntary Kernel Preemption (Desktop))

    3) Select and Enter on Preemption Model (Fully Preemptible Kernel (RT))

    4) After successful selection click on save button and then come back to main page using Esc button on keyboard.

Refer the following screen capture for more details

Steps to Apply RT Patch

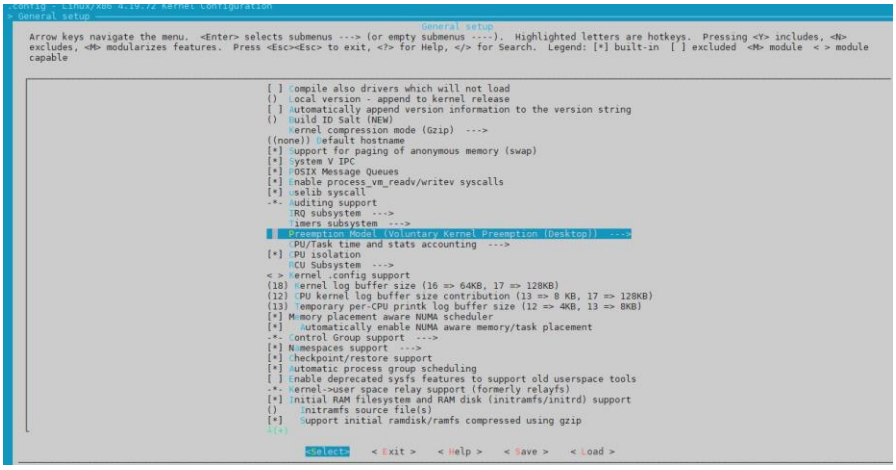


Figure 3 : Preemption Model (Voluntary Kernel Preemption (Desktop))

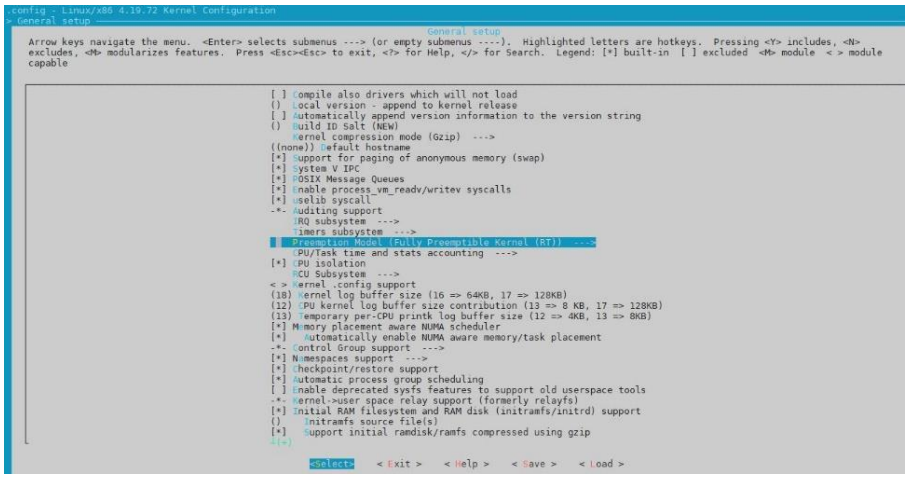


Figure 4: Preemption Model (Fully Preemptible Kernel (RT))

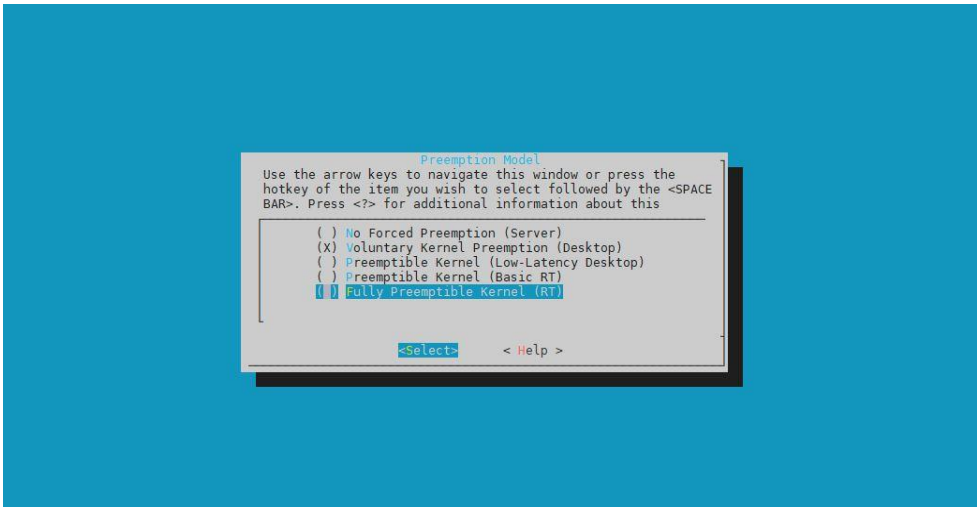


Figure 5: Fully Preemption Kernel (RT)

Save and exit

To save the current setting click on <save> button and then exit the UI using <exit> button.

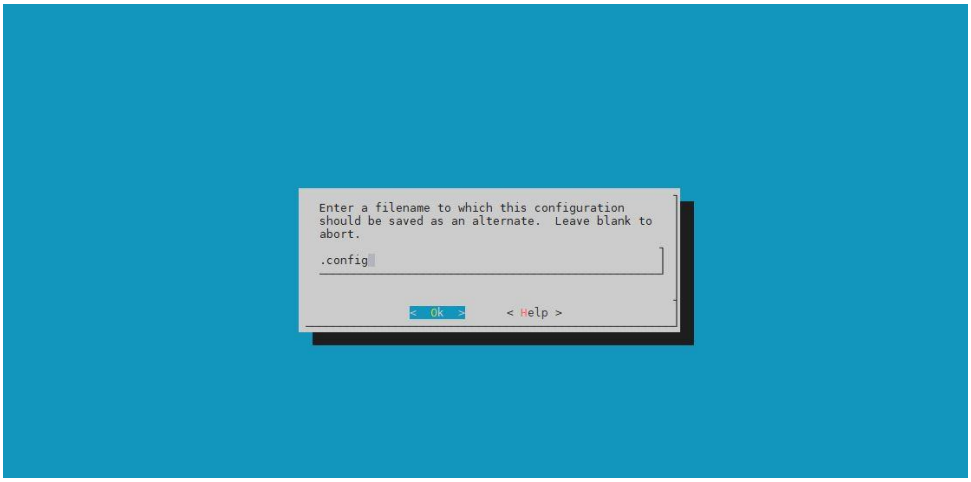


Figure 6: Click on 'OK'

7. Compile the kernel (Execute the following commands)

```
$ make -j20
$ sudo make INSTALL_MOD_STRIP=1 modules_install -j20
$ sudo make install -j20
```

8. Verify and update Verify that initrd.img-4.19.72-rt26, vmlinuz-4.19.72-rt26, and config-4.19.72-rt26 are generated in /boot directory and update the grub.

```
$ cd /boot
$ ls
$ sudo update-grub
```

   Verify that there is a menuentry containing the text "menuentry 'Ubuntu, with Linux 4.9.72-rt26'" in `/boot/grub/grub.cfg` file
   To change default kernel in grub, edit the `GRUB_DEFAULT` value in `/etc/default/grub` to your desired kernel.

   NOTE: 0 is the 1st menuentry

9. Reboot and verify using command

```
$ sudo reboot
```

   Once the system reboots, open the terminal and use `uname -a` to check the kernel version

   Command will show below output for successfully applied RT patch –

```
Linux ubuntu 4.19.72-rt26 #1 SMP PREEMPT RT Tue Mar 24 17:15:47 IST 2020 x86_64 x86_64 x86_64 GNU/Linux
```

14.0 Appendix

UWC contains below folders/files:

#	Folder/File	Destination	Comment
1	Modbus-master	IEdgeInsights/uwc	Modbus application folder used to install TCP/RTU container
2	MQTT	IEdgeInsights/uwc	It is used to install mosquito (mqtt) container
3	mqtt-bridge	IEdgeInsights/uwc	Mqtt-bridge application folder used to install mqtt-bridge container
4	sparkplug-bridge	IEdgeInsights/uwc	Sparkplug-Bridge application folder used to install Sparkplug-Bridge container.
5	kpi-tactic	IEdgeInsights/uwc	kpi-tactic application folder used to install kpi-app container.
6	Others	/opt/intel/eii/uwc_data/	All yml files containing device, datapoints etc. configurations. It also contains Global_config.yml
7	uwc_common	IEdgeInsights/uwc	Common libraries installation

Appendix

			docker file and source code.
8	build_scripts	IEdgeInsights/uwc	All installation scripts are kept here
9	uwc_recipes	IEdgeInsights/uwc	This directory contents recipe files