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28-29 SEPTEMBER 2021

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MIPI® I3C℠ Application and Validation Models for IoT Sensor Nodes

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- I3C: Overview
  - Evolution of MIPI I3C Interface specification
  - I3C Features and Uses
- I3C application to IoT Sensor Nodes
  - Sensor Node sub-systems
  - Communication among Sensor Node sub-systems
  - Using I3C for Sensor Node board communication
- I3C CTS and SysML as enablers toward an efficient validation
  - Why manage IoT systems complexity ?
  - How to manage IoT systems complexity ?
  - IBI use case validation management example
- Conclusions and Best Practices

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MIPI I3C Overview

Evolution of MIPI I3C Interface specification

I3C v1.0
- First Specification
- Released in 2016

2 wires interface
IBI for interrupt management
Hot-Join
1.2V – 3.3V support

I3C v1.1
- New I3C specification
- More features added
- Released in 2019

Multi-lane configuration
Structured IBI notification
Group Addressing
In-Band Reset function

I3C v1.1.1
- Updates on v1.1
- Released in 2021

Virtual devices use
Passive Hot-Join
Group management

I3C Features and Uses (1/3)

- Multi-lane configuration (introduced in v1.1)
  - Allows the I3C bus to extend the Data lines to two or 4 data lanes
  - This helps in increasing the data throughput using the same base clock
  - Dual-Lane and Quad-lane increase the effective data rate by 2x and 4x respectively
- Structured IBI notification (introduced in v1.1)
  - IBI can be accompanied by Mandatory Data Byte (MDB)
  - By defining a structured MDB format the efficiency of IBI usage can be increased
  - These updates include the pending read notification and timing control information

Comparison of Features

Feature	I3C v1.0	I3C Basic v1.0	I3C v1.1.1	I3C Basic v1.1.1
12.5 MHz SDR (Controller, Target and Legacy I²C Target Compatibility)	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Target can operate as I²C device on I²C bus and on I3C bus using HDR modes	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Target Reset	✔ (red)	✔ (red)	✔ (green)	✔ (green)
Specified 1.2V-3.3V Operation for 50pf C load	✔ (green)	✔ (green)	✔ (green)	✔ (green)
In-Band Interrupt (w/MDB)	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Dynamic Address Assignment	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Error Detection and Recovery	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Secondary Controller	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Hot-Join Mechanism	✔ (green)	✔ (green)	✔ (green)	✔ (green)
Common Command Codes (Required/Optional)	✔ (green)	✔ (green) / ✔ (red)	✔ (green)	✔ (green) / ✔ (red)
Specified 1.0V Operation for 100pf C load	✔ (red)	✔ (green)	✔ (red)	✔ (green)
Set Static Address as Dynamic Address CCC (SETAASA)	✔ (red)	✔ (green)	✔ (green)	✔ (green)
Synchronous Timing Control	✔ (green)	✔ (red)	✔ (green)	✔ (red)
Asynchronous Timing Control (Mode 0)	✔ (green)	✔ (red)	✔ (green)	✔ (green)
Asynchronous Timing Control (Mode 1-3)	✔ (green)	✔ (red)	✔ (green)	✔ (red)
HDR-DDR	✔ (green)	✔ (red)	✔ (green)	✔ (green)
HDR-TSL/TSP	✔ (green)	✔ (red)	✔ (green)	✔ (red)
HDR-BT (Multi-Lane Bulk Transport)	✔ (red)	✔ (red)	✔ (green)	✔ (green)
Grouped Addressing	✔ (red)	✔ (red)	✔ (green)	✔ (green)
Device to Device(s) Tunneling	✔ (red)	✔ (red)	✔ (green)	✔ (red)
Multi-Lane for Speed (Dual/Quad for SDR and HDR-DDR)	✔ (red)	✔ (red)	✔ (green)	✔ (red)
Monitoring Device Early Termination	✔ (red)	✔ (red)	✔ (green)	✔ (red)

I3C Features and Uses (2/3)

- Group Addressing (introduced in v1.1)
  - I3C is already has a broadcast and unicast communications
  - Group addressing allows devices to be assigned a Group address effectively creating a multicast system
  - The multicast is advantageous in sending data to a group of devices on the bus
  - Helps in grouping devices with different capabilities into a group i.e., multi-lane
  - Revised V1.1.1 allows groups to have a dedicated multilane configuration
- In-Band Reset function
  - This pattern-based reset function is aimed at making the I3C a true two wire interface
  - This will help in avoiding the use of a dedicated reset line
  - It has a configurable option where the reset can be escalated from a peripheral reset to whole chip reset
  - Useful in avoiding deadlocks on the bus due to an unresponsive device

I3C Features and Uses (3/3)

- Secondary Controller (introduced in v1.0 and updated in v1.1)
  - I3C is a true multi-drop interface
  - Built-in support for multiple controllers
  - Conflict avoidance and bus control management are already part of the protocol
  - Devices that are capable of being in control can request and give back control
- Low power consumption
  - I3C is a protocol that has been designed to support different voltage ranges
    - The standardized electrical behaviors can be adopted based on the design requirement
    - 1.2V – 3.3V
  - Low power applications can take advantage of these I3C features
    - High speed communication with the same base clock achieved through
      - HDR modes
      - Multilane communication
    - Low Voltage communications
  - Ideal for battery operated devices

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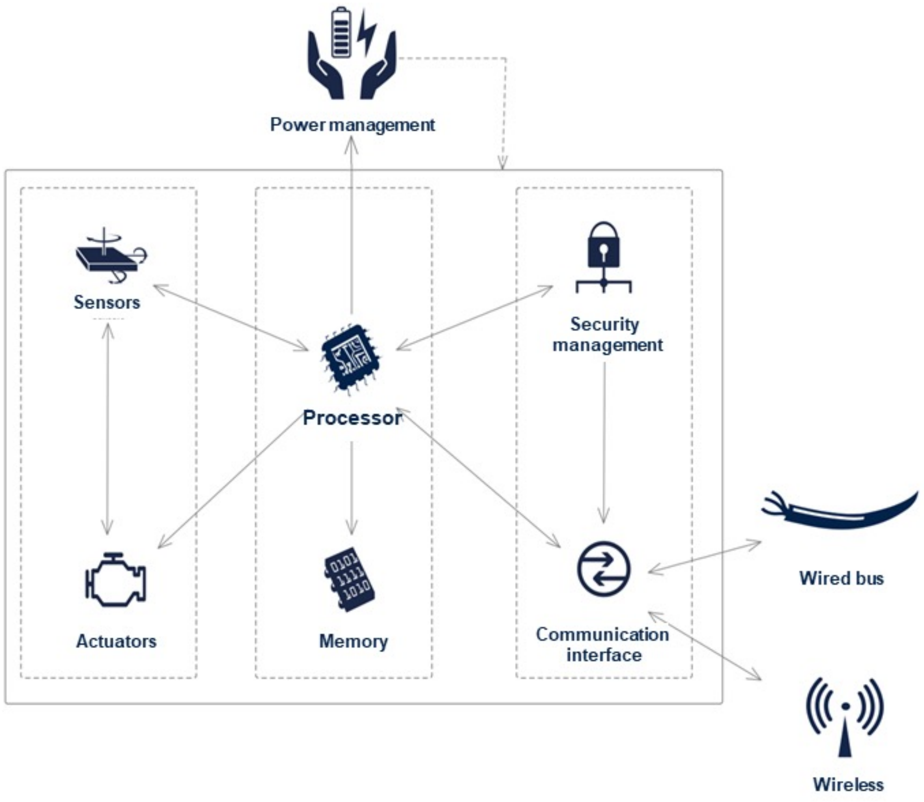
I3C Application to IoT Sensor Nodes

IoT Sensor Nodes

- Internet of Things (IoT) is a network that is made of physical objects that are capable of being connected to a network to make measurements or to execute given tasks.
- Critical elements of an IoT system are:
  - The communication element that manages device connectivity (**Internet**)
  - The sensing and processing system (**Things**)
- Sensor Nodes are basic elements of an IoT device that comprise the sensing and the connection element.

Sensor Node sub-systems

- A sensor node is an IoT device that is made of different components divided into subsystems.
- A sensor node consists the following subsystems:
  - *Sensing*: continuous small scale data generation
  - *Processing*: central processing based on configuration
  - *Communication* (wired/wireless): for connected devices
  - *Power supply*: battery subsystem for remote devices
  - *Memory*: data storage for later processing or backup to Memory
  - *Security*: all devices need to be secure from intrusion



Communication among Sensor Node sub-systems

- A sensor board communication could be divided in to two types based on the amount of data and frequency of communication

High **A**ctivity **L**ow **T**hroughput bus

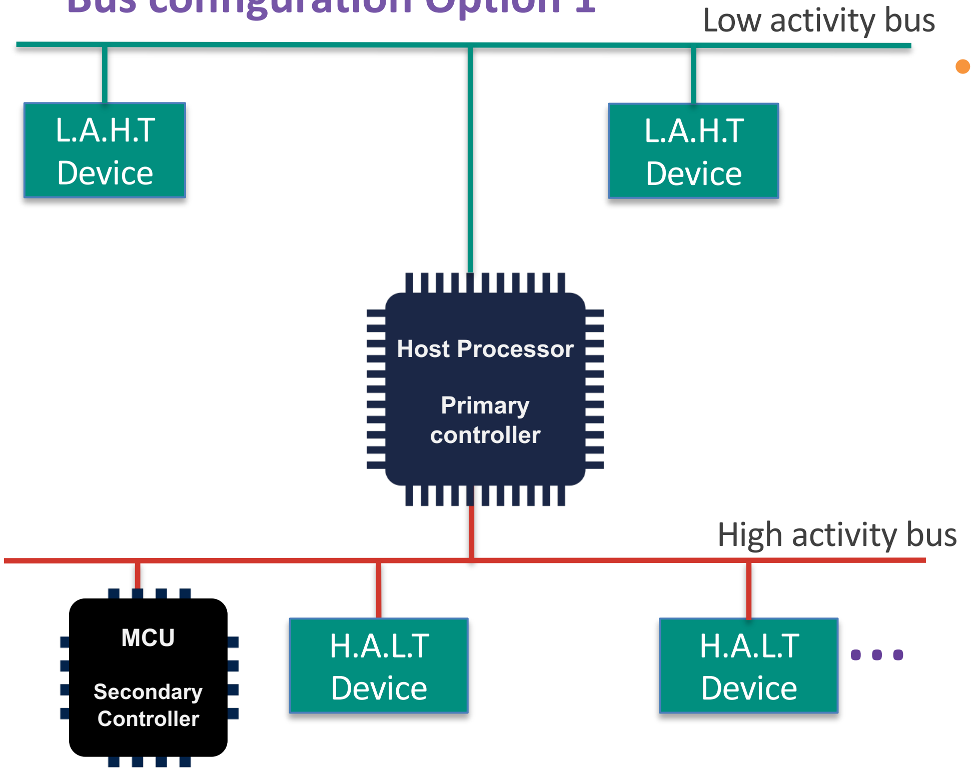
- H.A.L.T bus
- Short but frequent communications.
  - Sensing subsystem
  - Actuating subsystem
- Configuration of system
  - Power management
  - Subsystem configuration
- Frequent interrupts from sensing elements

Low **A**ctivity **H**igh **T**hroughput bus

- L.A.H.T bus
- Large data that require high throughput
  - Security Subsystem
  - Memory Subsystem
- Low latency communication
  - Communication subsystem
  - Memory Subsystem
- Periodic communication requests

Using I3C for Sensor Node board communication

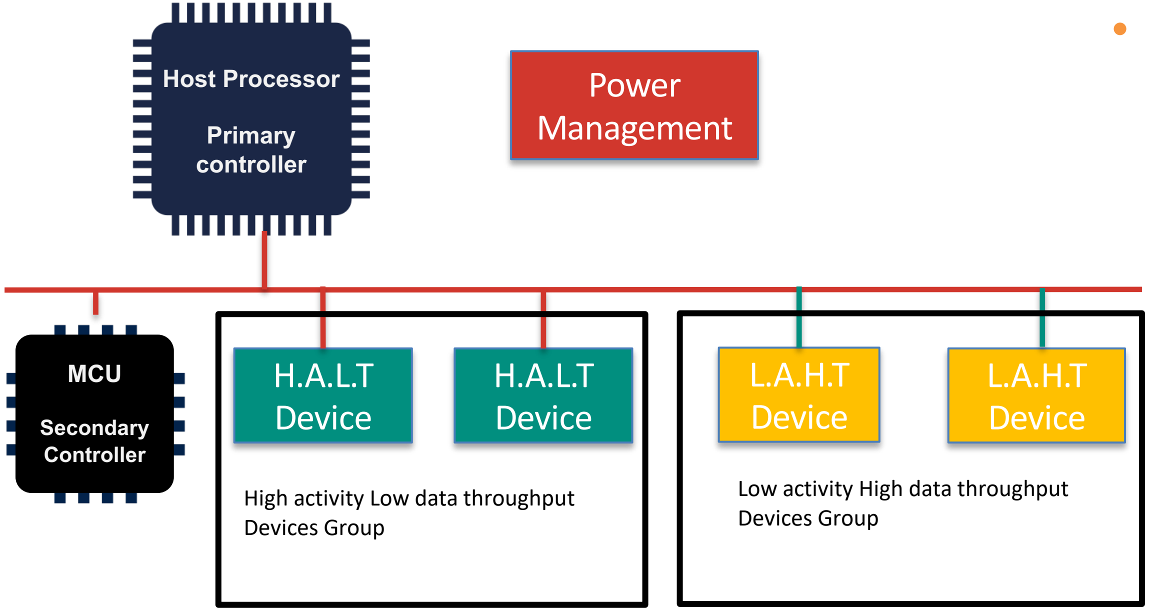
Bus configuration Option 1



- Use two buses for the two types of communication
  - Use a secondary controller to manage the high activity bus
  - L.A.H.T bus could use these I3C features for high data rate
    - Multi-Lane
    - HDR modes
  - H.A.L.T bus requires
    - Single lane due to continuous IBI
    - Secondary controller as a Sensor Hub to collect data from sensors

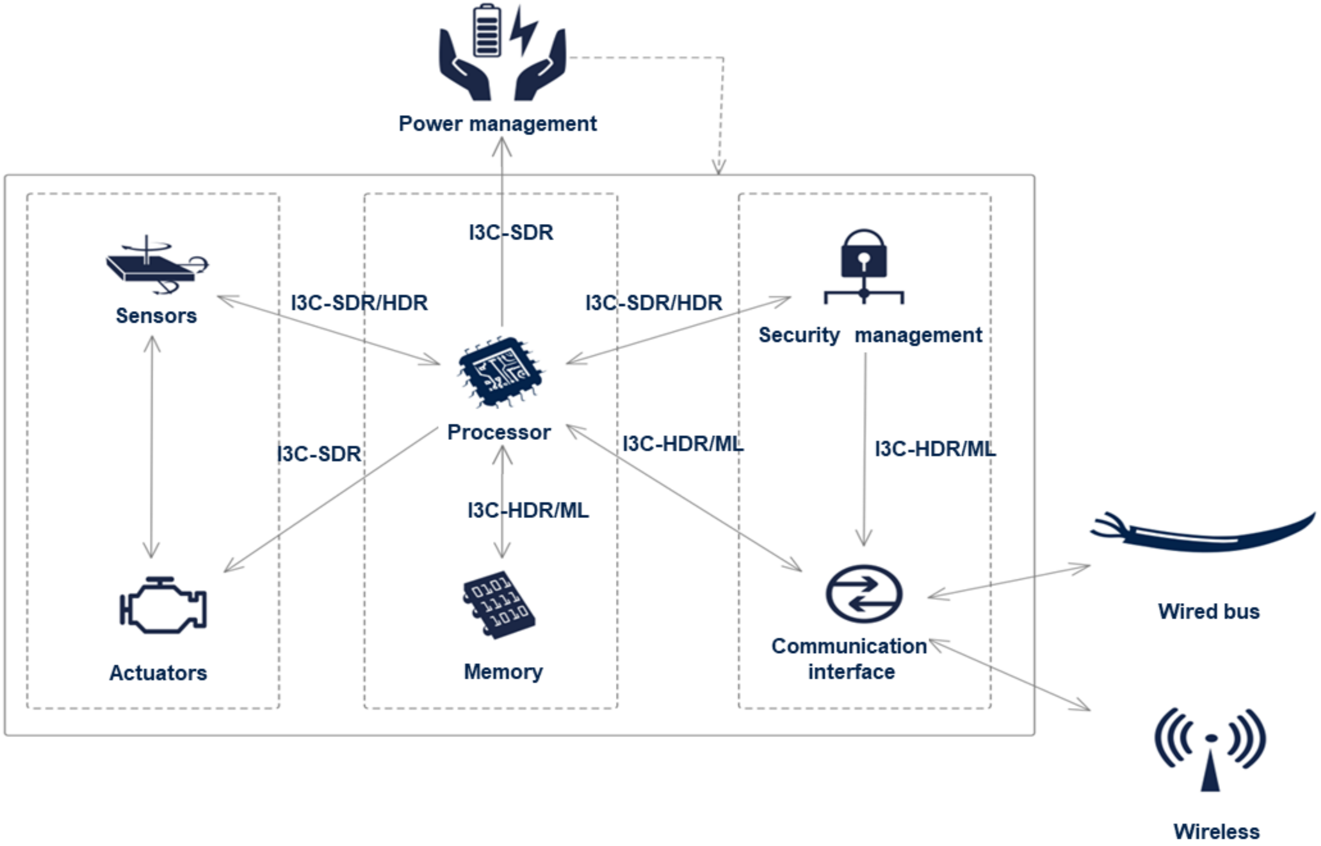
Using I3C for Sensor Node board communication

Bus configuration Option 2



- Take advantage of Group addressing
- Two groups with dedicated features per group
  - Group 1: H.A.L.T
    - Group of devices that use the single lane features
    - Devices in this group can send IBI
  - Group 2: L.A.H.T
    - Grouped to use multilane configuration for higher throughput
    - Devices in this group may not require the IBI capability

Sensor Node reference board communication using I3C



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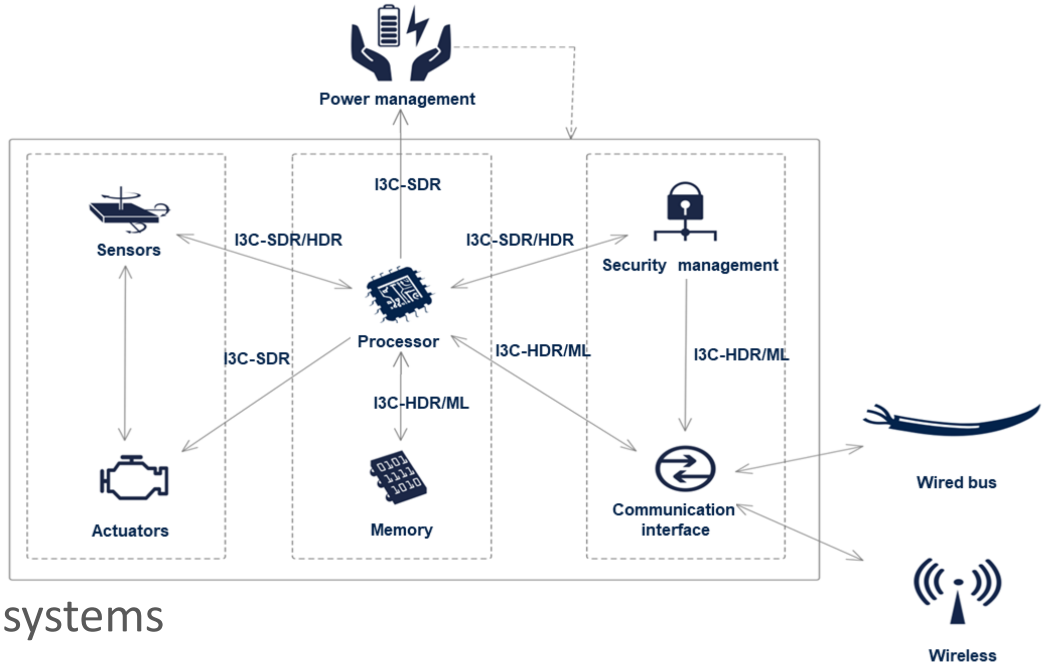
I3C CTS and SysML as enablers toward an efficient validation

Why manage I3C IoT systems complexity?

- Systems are:
  - More and more complex,
  - More and more connected,
  - More and more critical,
  - More and more secured,
  - More and more standardized



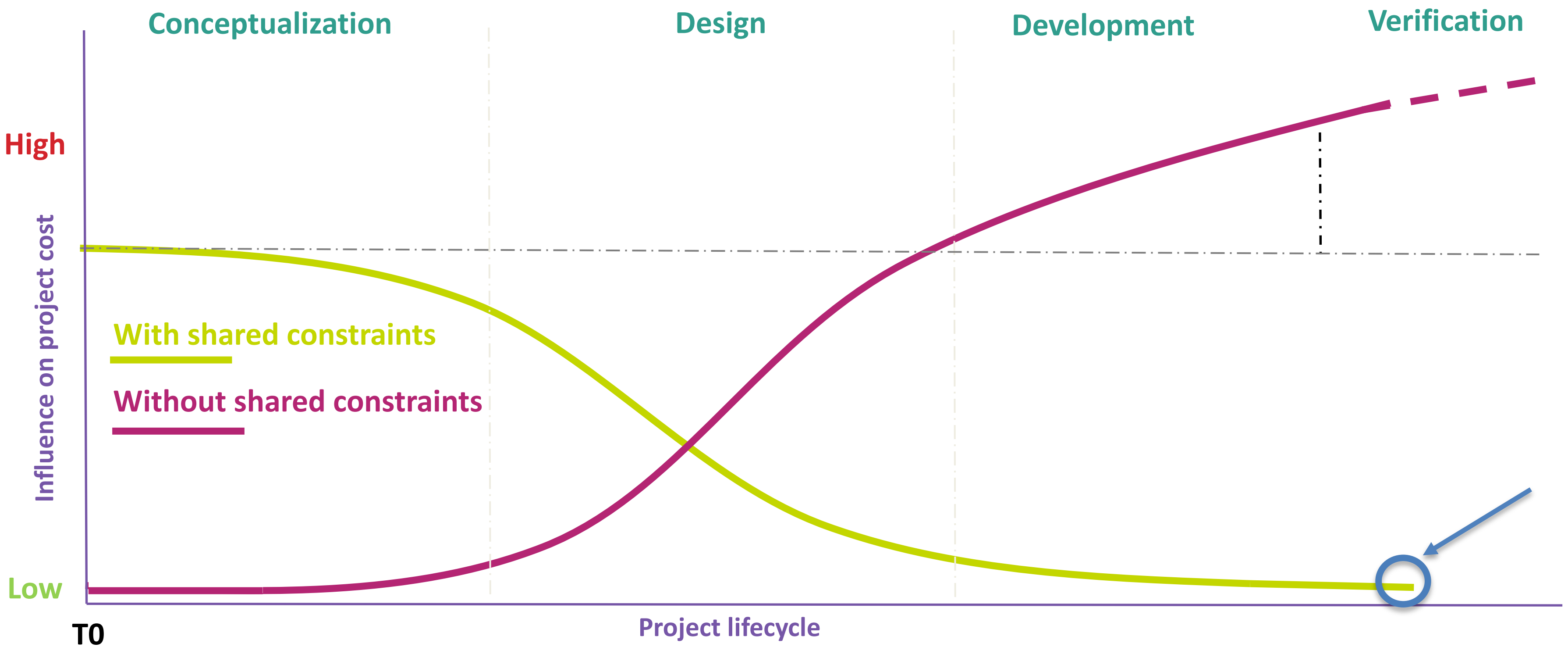
- Project management needs:
  - Effective collaboration
  - Good understanding of (sub-)systems
  - Best anticipation as possible
  - Effective design, development and verification

Why manage I3C IoT systems complexity?

- Targets:
  - To build a global and shared vision
  - To identify needs and constraints
  - To synchronize all stakeholders + constraints between themselves
  - To be efficient with trade-offs and optimizations

- In a nutshell:
  - By setting of adequate activities to design, develop, and verify a system while satisfying all stakeholders

Why manage I3C IoT systems complexity?



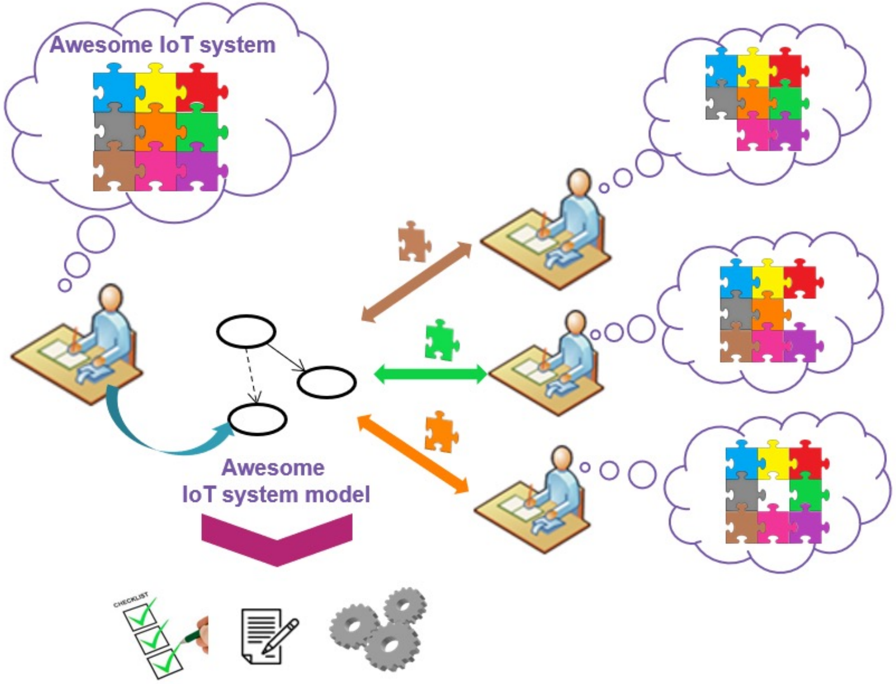
Why manage I3C IoT systems complexity?

- Digital communication interfaces = A choking point of the global performance of the system
- Sensor node example with I3C interface as subsystem:
  - 2 modes + HDR sub-modes
  - Backward compatibility
  - Multi-role
  - I3C Built-in features

→ **I3C = Powerful system enabler**

How to manage IoT systems complexity?

- One interesting path: By building the model of the system:



→ **System modeling as an enabler**

How to manage IoT systems complexity?

Inputs

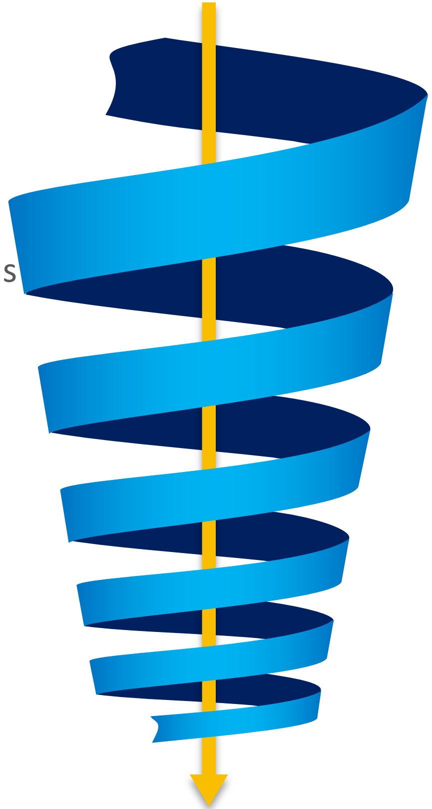
Requirements model

- Use cases diagrams
- Requirement diagrams
- Test cases diagrams

Architecture model

- Packages diagrams
- (…)

Dynamic model

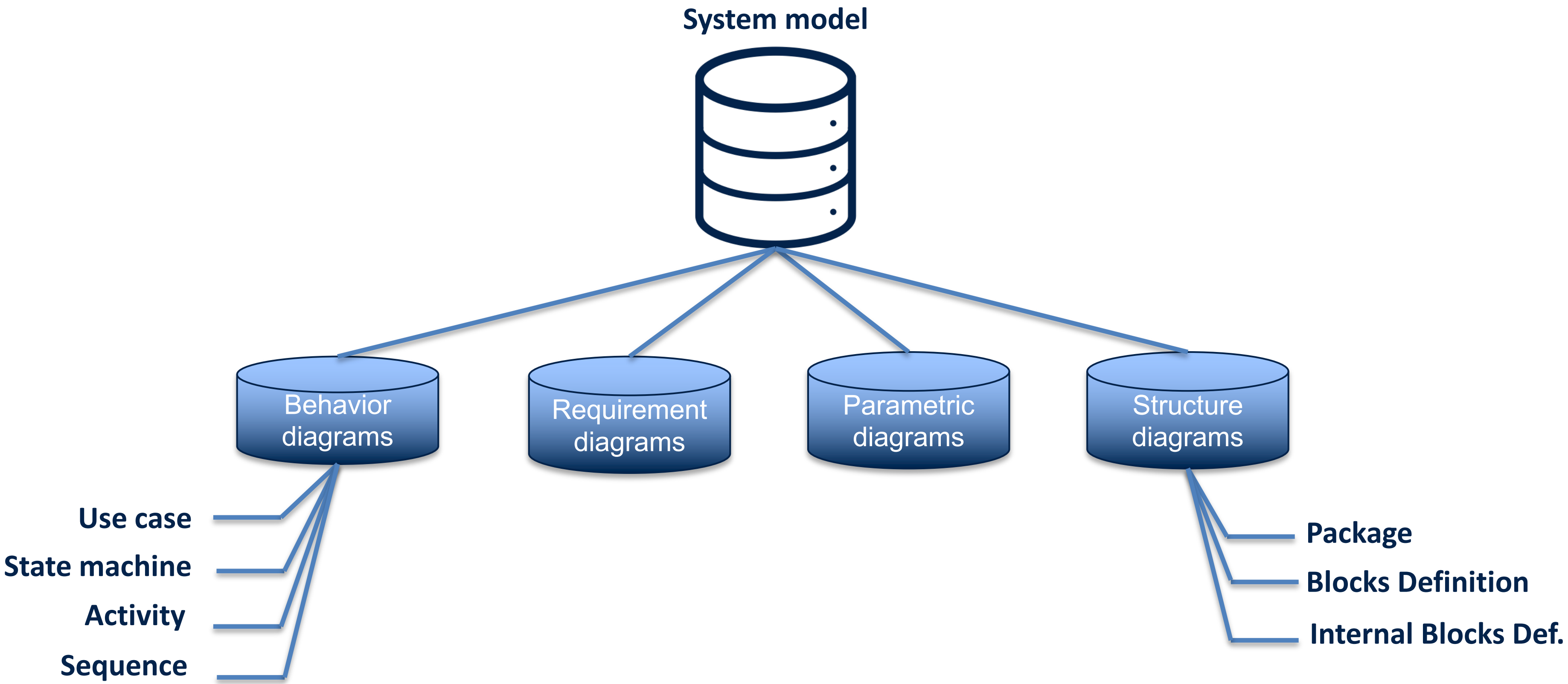


Traceability

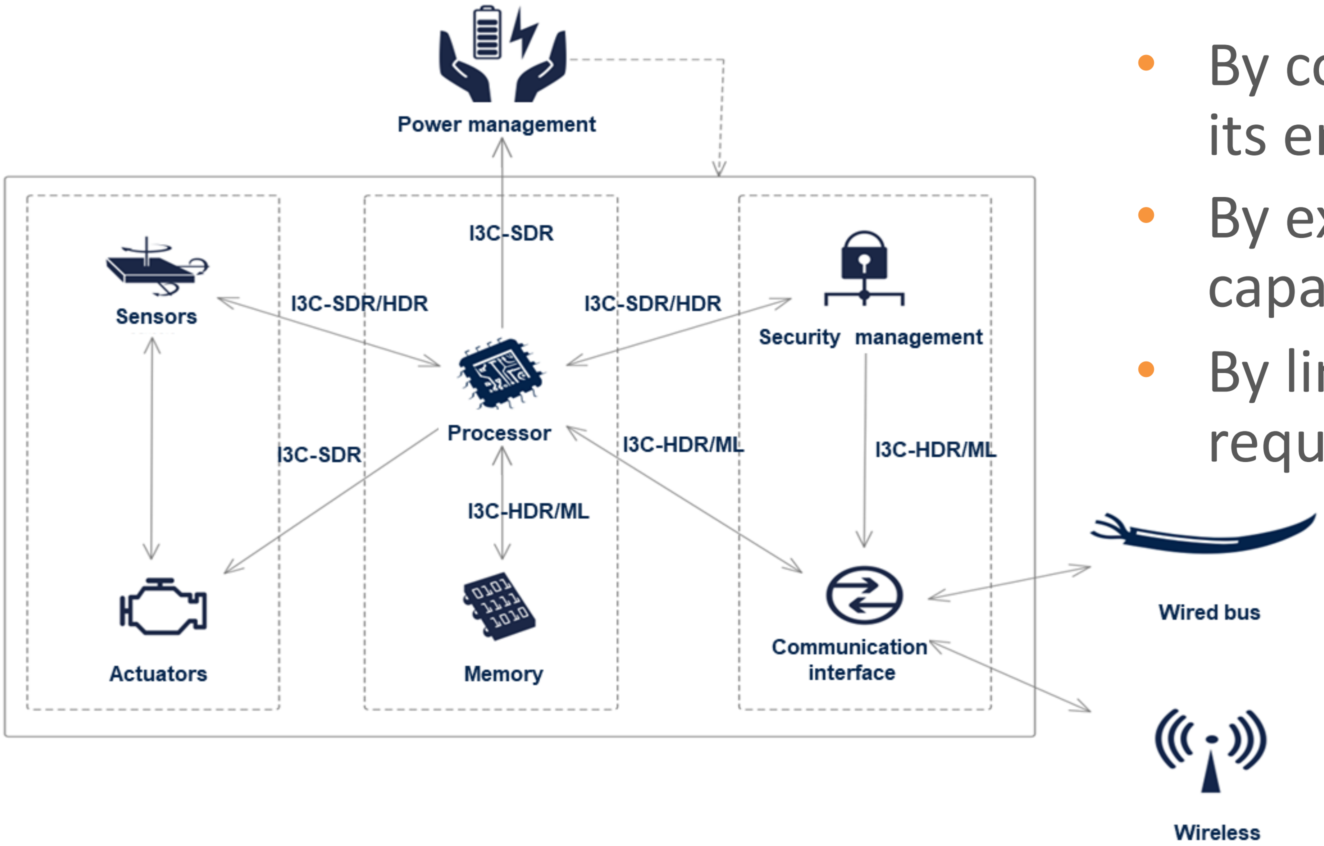
Allocation

Detect issues earlier

How to manage IoT systems complexity?

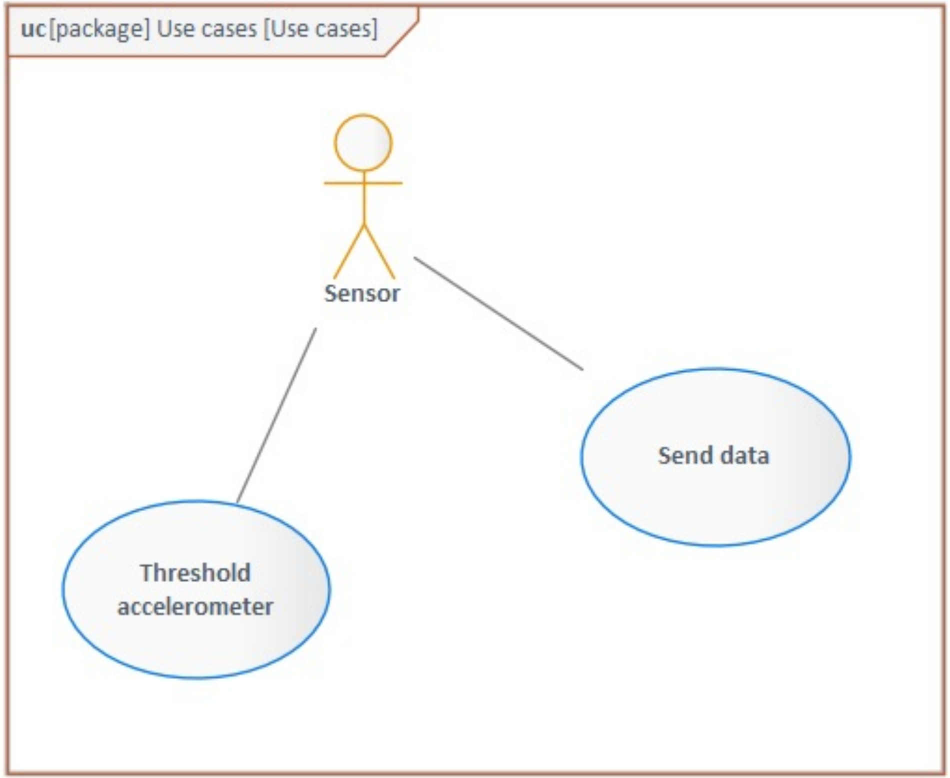


Example of I3C Sensor Node



- By considering system in its environment,
- By exploring all interface capabilities
- By linking and crossing all requirements:
  - Technical,
  - Functional,
  - Standards,
  - Validation,
  - …

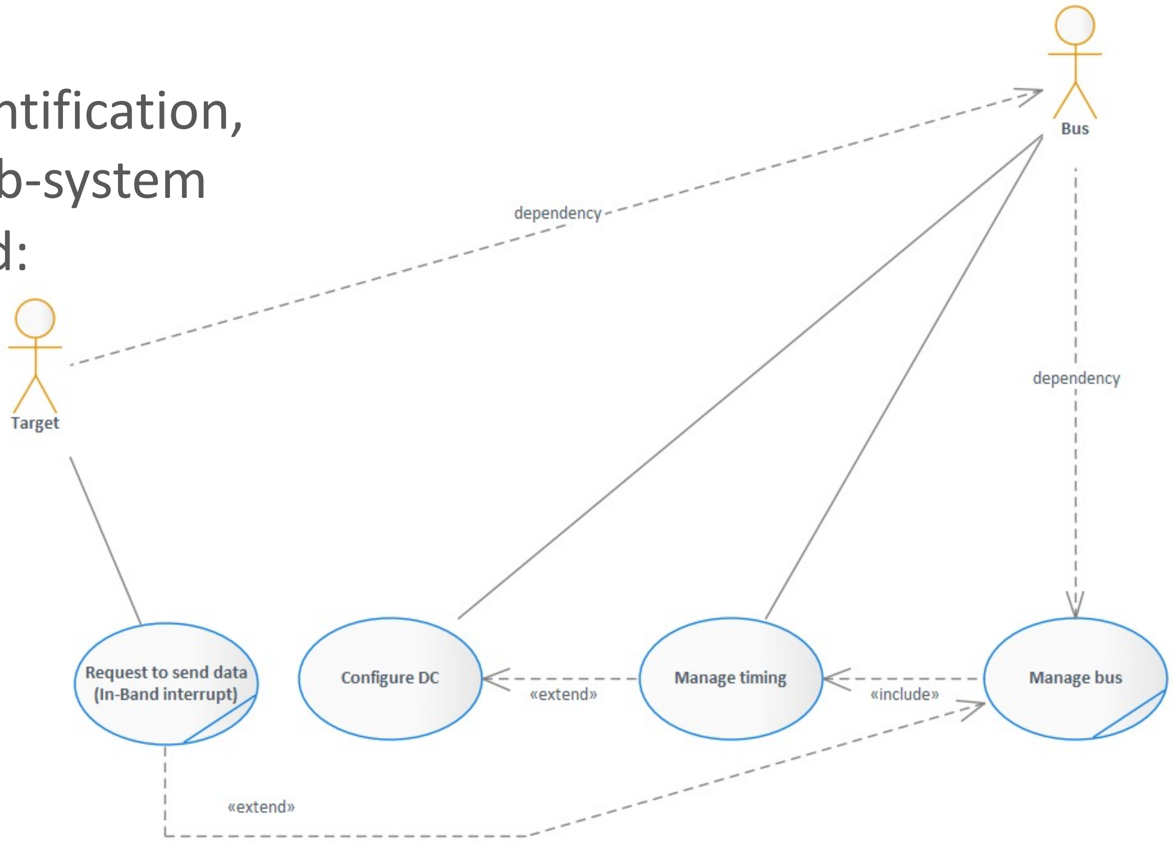
Example of I3C Sensor Node



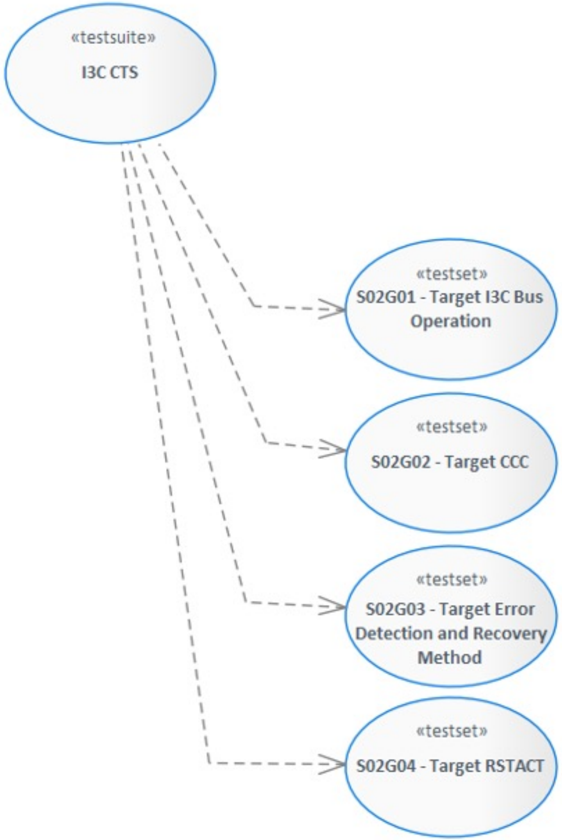
- High level system description
  - Nominal scenario
  - Alternate scenario
  - Error scenario
- (Sub) Systems stakeholders identification

Link to I3C use cases

- High level dependance identification,
- Stowage link with other sub-system
- Model of MIPI I3C standard:
  - Cross view,
  - No “hidden” constraints,
  - Items identified earlier

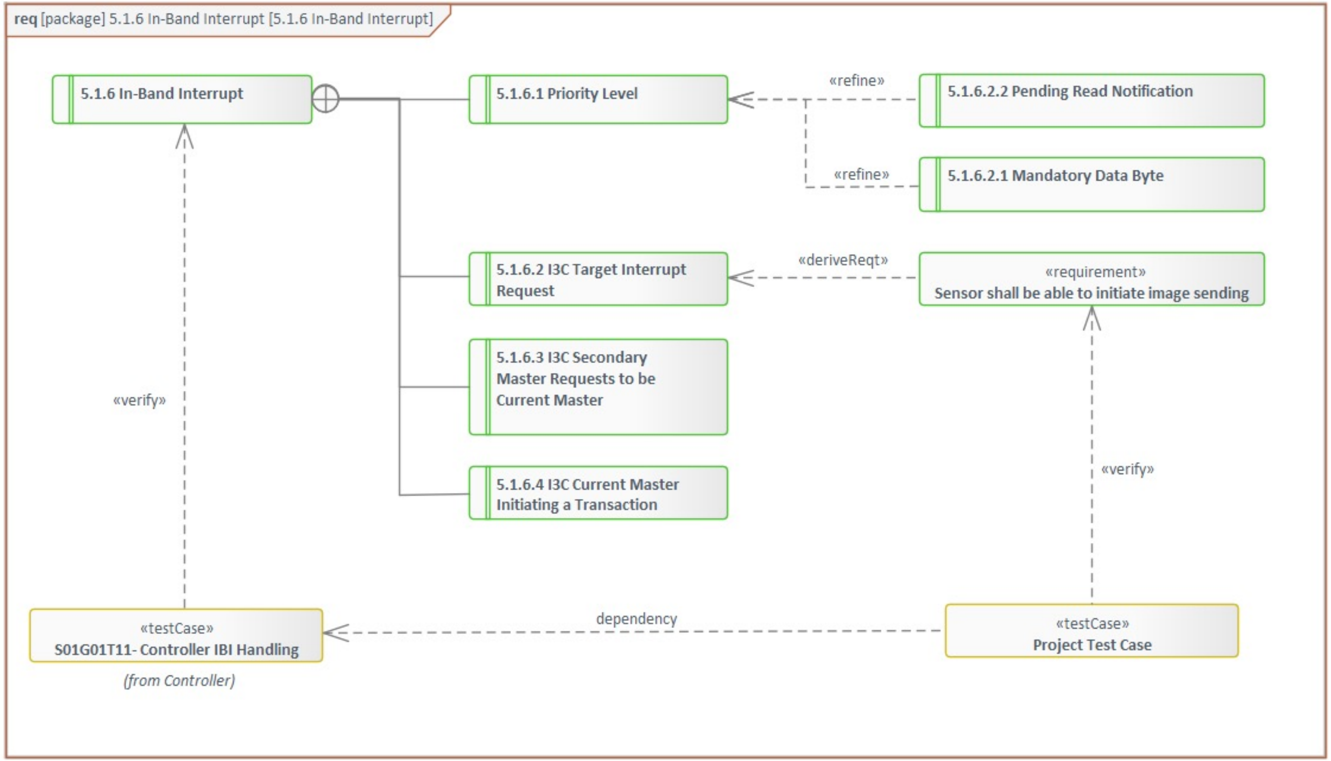


Link to CTS use cases



- Identification of dependances or constraints by dynamic links
- Example: I3C standard and CTS model help to not forgot items to implement

Focus on demand



Capabilities to dive into:

- Standard
- CTS
- Project

Conclusions and Best Practices

- Advanced features allow easy adoption of MIPI I3C
- MIPI I3C: A scalable and flexible solution for IoT Sensor Node
- CTS as a starting point for I3C protocol validation
- CTS as an enabler to model your complex system validation
- Advanced systems validation model can be built on top of CTS

ADDITIONAL RESOURCES

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- MIPI® I3C®Specifications
  - https://www.mipi.org/specifications/i3c-sensor-specification
- MIPI® I3C® System Integrator App Note
  - https://www.mipi.org/sites/default/files/mipi_I3C-and-I3C-Basic_app-note-system-integrator_v1-0p.pdf
- MIPI® I3C® FAQ
  - https://www.mipi.org/resources/I3C-frequently-asked-questions
- MIPI® I3C® CTS
  - https://www.mipi.org/faq-category/conformance-testing
- STMicroelectronics MEMS Sensor products
  - https://www.st.com/en/mems-and-sensors.html#overview

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