IoT MAD LAB

UNA CIUDAD CONECTADA

Reference IoT Network Architecture for IoT in Smart Urban Spaces

MADRID Coordinación General de la Alcaldía

Capital Digital

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CeDInt POLITÉCNICA

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Introduction

This document describes the reference IoT network architecture for the city of Madrid, promoted by IoTMADLab. The objective of this architecture is to achieve **direct interoperability between IoT devices**, which can be from different manufacturers, and even from different municipal services. IoTMADLab focuses on the lower levels of the IoT ecosystem, i.e. at the network level, including the connectivity layer and the data model (see Figure 1).

In IoT applications for Smart City one of the necessary requirements is a reduced overhead in the encoding of information and the use of lightweight communication protocols to reduce the amount of information transmitted and the processing needs so that simple low-cost and resource-consuming devices can be used. It is also important that the data model and protocols used are based on open, mature standards that are widely implemented in the field of information technologies. This simplifies the development of devices and applications by different actors, allowing the development of an ecosystem of products and projects that favor competitiveness and innovation.

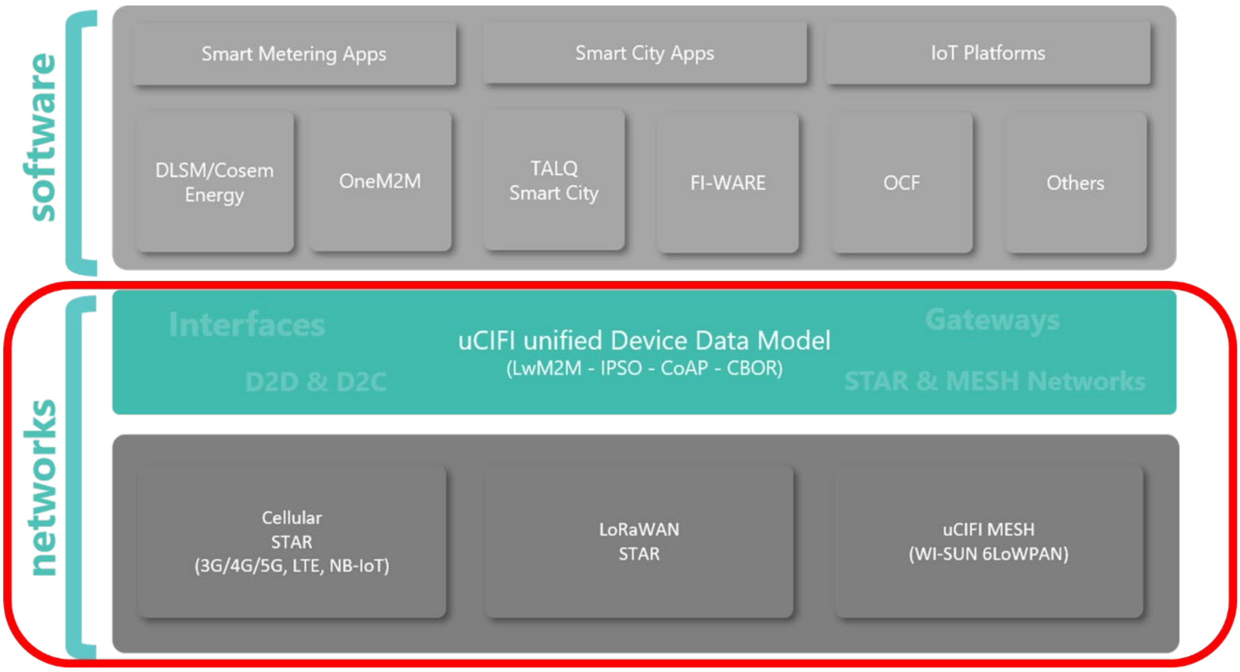

Figure 1. IoTMADLab focuses on the layers closest to the devices in the IoT Architecture.

The IoTMADLab reference architecture consists of two main components:

- A **data model**, publicly available through OMA Specworks[1].
- **Connectivity technologies**, prioritizing the use of mesh networks (**Wi-SUN**), which can integrate seamlessly with the data model.

[1] Select uCIFI owner in https://www.openmobilealliance.org/lwm2m/resources/registry/objects

Data Model

The data model defines the logical structure of the information associated with asset monitoring, management and control application such as a city's public lighting system. It can also define the protocols for accessing and communicating this information. To ensure the interoperability of the systems that make up the application and avoid dependence on a single vendor lock-in, the data model must be based on open specifications standardized by independent entities unaffected by commercial interests.

The data model, based on uCIFI works as reflected in OMA[2], is designed to allow device interoperability in Smart City applications. It can be used and/or adapted with the following protocols: LwM2M, IPSO, CoAP, and CBOR.

LwM2M

Lightweight M2M is an open protocol from the Open Mobile Alliance (OMA) designed to address the needs of low-power, low-resource IoT devices. LWM2M is being widely adopted by telecom operators and is emerging as the standard protocol for device management and service enablement.

The LwM2M standard defines the application layer communication protocol between an LwM2M server and an LwM2M client that resides on an IoT device. It provides an approach for managing IoT devices and allows devices and systems from different vendors to coexist in an IoT ecosystem. LwM2M was originally built on the CoAP protocol, but later versions of LwM2M also support application protocols.

LwM2M's device management capabilities include remote provisioning of security credentials, firmware updates, connectivity management, remote device diagnostics and troubleshooting. In addition, LwM2M services include sensor readings, remote activation and host device configuration.

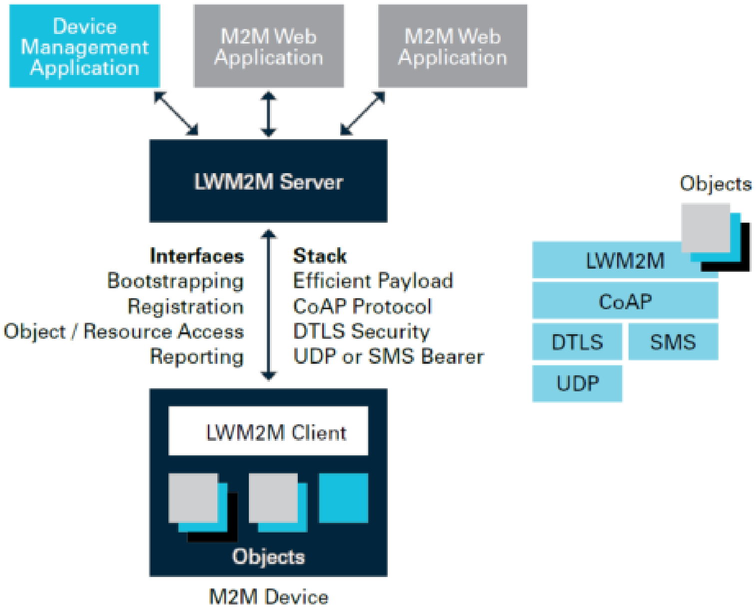

Figure 2. Logical communication interfaces between LwM2M Client and LwM2M Server.

[2] As of December 2024, uCIFI becomes part of OMA SpecWorks by transferring its specification work and establishing a new working group called "Smart City" to be created within OMA. The uCIFI data model will continue to be developed by this group within OMA.

IPSO

IPSO Smart Objects, developed by OMA SpecWorks, provide a structure for defining device objects, which are collections of resources that a device collects, stores, and exposes to external applications. IPSO Smart Objects specifications include human-readable definitions, technical specifications, and extended descriptions for each object, facilitating IoT system implementation. These objects are designed for use with multiple protocols supporting data types, URI addressing, content formats, and basic operations (read, write, execute). They can be employed in protocols like CoAP, HTTP, and even MQTT (with some adaptation work).

Object Name	ID	Instances	Object URN
Temperature Sensor	3303	Multiple	urn:oma:lwm2m:ext:3303

Resource	ID	Oper.	Mandatory	Type	Units	Description
Sensor Value	5700	R	Mandatory	Float	Defined by "Units" resource	Current measured sensor value
Min Measured Value	5601	R	Optional	Float	Defined by "Units" resource	The minimum value measured by the sensor since power ON
Max Measured Value	5602	R	Optional	Float	Defined by "Units" resource	The maximum value measured by the sensor since power ON
Min Range Value	5603	R	Optional	Float	Defined by "Units" resource	The minimum value that can be measured
Max Range Value	5604	R	Optional	Float	Defined by "Units" resource	The maximum value that can be measured
Sensor Units	5701	R	Optional	String		Measurement units definition e.g. "Cel" for celsius
Reset Min and Max Measured Values	5605	E	Optional	String		Reset the min and max measured values to current value

Figure 3. Example of an IPSO object for a temperature sensor.

CoAP

CoAP (Constrained Aplication Protocol) is a specialized Internet application protocol for low-resource devices. It is standardized in the RFC 7252 specification of the Internet Engineering Task Force (IETF), which is responsible for the technical standards that make up the Internet protocol suite. The IETF "CoRE" Working Group has done the main standardization work with the goal of making the protocol suitable for IoT and M2M applications.

CoAP uses UDP at the transport level, one of the standard Internet protocols. It is also intended to be easily translated to HTTP for simplified integration with the web, while meeting IoT device requirements such as multicast support, very low overheads and simplicity. CoAP is an easy-to-integrate protocol and can be easily paired with applications that use cross-protocol proxies. It integrates seamlessly with JSON, XML, CBOR and other data formats.

The smallest CoAP message is 4 bytes long, if the token, options and payload fields are omitted, i.e., if it consists only of the CoAP header. Any bytes after the header, token and options (if any) are considered the payload of the message, which is prefixed with the one-byte "payload marker" (0xFF). The payload length is variable and is implicit in the datagram length.

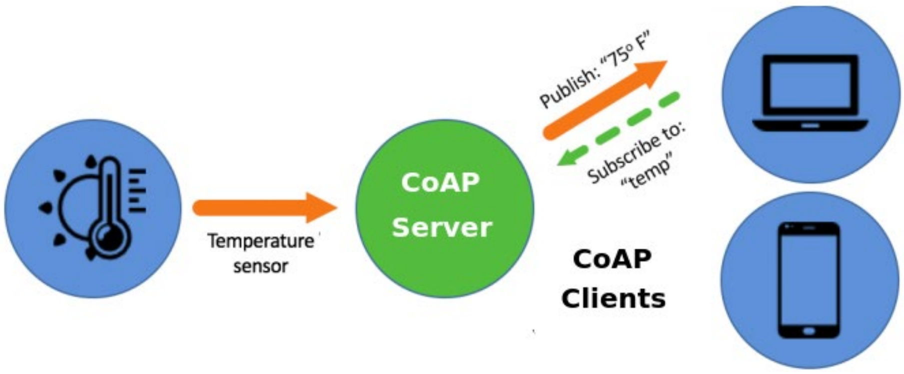

Figure 4. CoAP employs a request/response communication model.

CBOR

CBOR ("Concise Binary Object Representation") CBOR ("Concise Binary Object Representation") is a binary data serialization format based on JSON. Like JSON, it allows the transmission of data objects containing name and value pairs, but in a more concise manner. This increases processing and transfer speeds at the expense of human readability. It is standardized by the IETF in RFC 8949.

CBOR-encoded data is viewed as a stream of data elements. Each data element consists of a header byte containing a 3-bit type and a 5-bit short counter. This is followed by an optional extended counter (if the short counter is in the range from 24 to 27) and an optional payload.

Various encoder and decoder implementations of the format exist in different programming languages and with different licenses for use.

Plain Text JSON	CBOR Binary Data	CBOR Decode
{ "Name": "Sam" }	A1 64 4E 61 6D 65 63 53 61 6D	A1 # map(1) 64 # text(4) 4E616D65 # "**Name**" 63 # text(3) 53616D # "**Sam**"

Figure 5. Example of CBOR encoding.

Connectivity Technologies

After analyzing the current connectivity technologies, we have selected those that are (or may be in the future) compatible with the data model and that, due to their characteristics, cover all the requirements of the possible use cases.

For the first phase of the Smart Urban Spaces implementation, WI-SUN has been chosen since it has a wide range of applications and its compatibility with the data model has been reliably validated.

WI-SUN

The Wi-SUN (Wireless Smart Ubiquitous Network) Alliance is formed by more than 250 companies (microchip vendors, software vendors, service companies, academic institutions, government and regulatory agencies) and defines the Wi-SUN FAN (Field Area Network) specification, which has given rise to the IEEE 2857-2021 standard, a mesh network protocol, which works over 6LoWPAN and is based on several IETF, IEEE and ANSI/TIA standards.

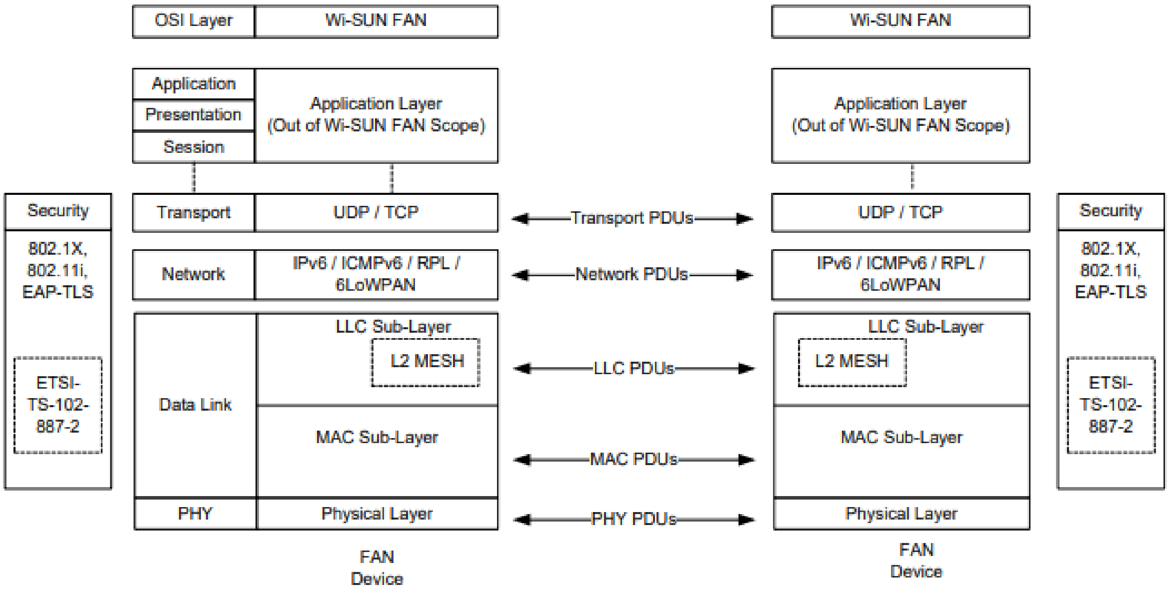

Figure 6. Wi-SUN protocol stack.

6LoWPAN (IPv6 over Low Power Wireless Personal Area Network) is a communication standard designed to enable connectivity of low power and resource-limited devices over wireless personal area networks (WPAN) based on IEEE 802.15.4. 6LoWPAN is based on Internet Protocol Version 6 (IPv6), which allows assigning unique IP addresses to each connected device, facilitating its identification and communication in the network. This feature is essential for the deployment of many devices, as it provides a scalable and flexible infrastructure.

Wi-SUN (6LoWPAN) implements a mesh network topology, which enables direct communication between devices and uses a hierarchical and self-organizing routing approach, where nodes act as routers to relay packets between devices. Thanks to the mesh topology, several hundred meters can be reached, depending on the frequency used (868 MHz and 2.4 GH free bands). Transmission rates can range from a few tens of kilobits per second to a few hundred kilobits per second - depending on the band used, the consumption requirements of the devices and the desired range. In terms of security, encryption and authentication mechanisms (128-bit AES) are used to protect communication between devices and the network.

Reference Mesh Implementation of Wi-SUN

To ensure interoperability between devices from different manufacturers and services, the following communication parameters have been defined within the Wi-SUN FAN specification that are compatible with the (future) Wi-SUN reference mesh implementation (programmable via firmware):

- Frequency bands: EU1 (863-870 MHz) and EU2 (870-876 MHz).
- PHY mode of operation: 2a (100kbps).

Complementary connectivity technologies

To cover all possible use cases and respond to special location, power or communication requirements, the future incorporation of LoRaWAN and NB-IoT (after validation of their compatibility with the data model) is contemplated.

Conclusions

The IoTMADLab reference architecture is based on a standardized **data model** (LwM2M, IPSO, CoAP, CBOR) and Wi-SUN **connectivity technology** (6LoWPAN, 868 MHz, 2a).

IoTMADLab has the infrastructure to test equipment that meets these specifications and establishes the criteria for issuing its compatibility and interoperability reports based on what is specified in this document.

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