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Internet of Things (IoT) – Overview and general requirements of IoT system for ecological environment monitoring

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INTERNET OF THINGS (IoT) – OVERVIEW AND GENERAL REQUIREMENTS OF IoT SYSTEM FOR ECOLOGICAL ENVIRONMENT MONITORING

FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting
JTC1/SC41/316/FDIS	JTC1/SC41/329/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, available at www.iec.ch/members_experts/refdocs and www.iso.org/directives.

INTRODUCTION

The IoT-based ecological environment monitoring system is mainly for collecting data and monitoring the ecological environment entities (i.e. physical things in the IoT sense – air, water, soil, and living organisms) using various types of sensing devices. Such sensing devices include but are not limited to the following: growth meters for plant growth; infrared digital cameras and video cameras for identifying animal movements; tracking devices for position and location reporting; and physical, biological or chemical sensors for air, water, and soil monitoring. The collected data are transmitted via a network infrastructure, analysed for their relationships and evaluated for the trends of the eco-environment being monitored. With the current IoT and related technologies, for example, information and communication technologies, all these capabilities can be performed in real-time. Therefore, the IoT-based monitoring system satisfies the requirement of the real-time eco-environment monitoring and management in terms of data capture, data analytics, early warning services, and disaster management and emergency management. This system supports the decision-makers, for example, eco-environment managers, government agencies, and citizens, in the maintenance of the ecosystem and in correcting and restoring the ecosystem when damaged or polluted ecological environment is detected.

Eco-environment has been greatly altered with the development of the economy and humanity. The alteration of the eco-environment endangers the health of all living organisms including humans. More efforts to monitor and protect the earth's eco-environment will improve understanding and support corrective actions.

A number of regional scale eco-environment observation networks are constructed to monitor the ecosystem of air, water, soil, plants, animals. Examples of these regional eco-environment observation networks are GEMS (Global Environment Monitoring System), GTOS (Global Terrestrial Observing System), and ILTER (International Long Term Ecological Research). National scale eco-environment observation stations also exist to monitor water, forest, grassland, farmland, lakes, rivers and coastline. These national scale observation stations are parts of global eco-environment observation networks.

The trends of the eco-environment observation stations require united data sharing and networking, being standardized and automated, and likely to become intelligent. These trends are likely to become the requirements of eco-environment monitoring systems. Therefore, IoT-based systems can be applied to the eco-environment observation systems and networks to meet these requirements. The IoT-based eco-environment monitoring system can provide the accurate and comprehensive sensing of the physical entities (i.e. air, water, soil, and living organisms), reliable data transmission and reception, and intelligent information processing.

Since the 1990s, sensor network systems, which transitioned to the most essential part of the IoT-based systems in the 2000s, have been used for monitoring the environment quality, pollution, and living organisms. For example: the CitySense system in the US was developed for real-time monitoring of the environmental pollution in the city; multitudes of air quality monitoring systems have been deployed to monitor air quality and pollution all over the world; China has initiated the sandstorm and acid rain monitoring system; UC Berkeley is monitoring the birds in Great Duck Island; and Australia monitors underwater temperature and brightness of light to protect the coral reef.

Using the IoT technologies for ecological environment monitoring brings the following advantages in the ecosystem monitoring and management:

1) transforming from a single-point monitoring station to a multi-point network monitoring application through networking and data sharing;
2) ensuring the real-time and dynamic observation and measurements by effectively adapting to the monitored objects' complexity and variability compared to the measurements made manually and by legacy systems;
3) enabling pro-active actions toward ecological events in advance rather than reacting after the events take place;

4) realizing a multi-level and unified management of the observation stations and systems;
5) observing the entire ecosystem rather than geographically divided areas or regions (i.e. by using a single point observation) in both macro and micro perspectives; and
6) analysing the relationships among ecological entities to ensure the sustainable ecosystem and its development.

Standardizing the IoT-based eco-environment monitoring systems brings the benefits such as the enablement of on-demand, real-time monitoring for eco-environment, the improvement in the interoperability among all standardized eco-environmental monitoring systems which include hardware and software to realize the EEM worldwide, the full utilization of the observed data for various kinds of eco-environment applications referring to comprehensive functions and services of EEM system including analysis of the relationships between various ecological entities, and the study of the changing trends of the ecosystem.

IoT-based monitoring systems also bring benefits for relevant stakeholders, including the users and builders of the IoT-based eco-environment monitoring systems. The users include the following:

– public users, citizens, data scientists for eco-environment;
– the monitoring organizations such as city environment monitoring organizations and wild area ecosystem monitoring organizations; and
– government agencies responsible for managing the entire ecosystem.

The builders are the developers of the communication modules and integrated devices, sensing devices, and monitoring service platforms for the IoT-based eco-environment monitoring systems.

INTERNET OF THINGS (IoT) – OVERVIEW AND GENERAL REQUIREMENTS OF IoT SYSTEM FOR ECOLOGICAL ENVIRONMENT MONITORING

1 Scope

This document specifies the Internet of Things system for ecological environment monitoring in terms of the following:

– system infrastructure and system entities of the IoT system for ecological environment monitoring for natural entities such as air, water, soil, living organisms; and

– the general requirements of the IoT system for ecological environment monitoring.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 9834-8:2014, *Information technology – Procedures for the operation of object identifier registration authorities – Part 8: Generation of universally unique identifiers (UUIDs) and their use in object identifiers*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
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3.1
ecological environment monitoring
EEM
process or activity that uses physical, chemical, biochemical, ecological and other technologies for the purpose of reflecting accurately, comprehensively, and in a timely manner the various elements of the ecological environment, the relationship between organisms and the environment, and the change trend of the ecosystem

Note 1 to entry: Elements of the ecological environment include air, water, soil, and living things.

4 Symbols and abbreviated terms

ASD	Application and Service Domain
EEM	ecological environment monitoring
GDPR	General Data Protection Regulation
GIS	geographic information service
HMI	human–machine interface

IoT	Internet of Things
IP	Internet Protocol
OMD	Operations and Management Domain
PED	Physical Entity Domain
QR	quick response
RAID	Resource Access and Interchange Domain
RFID	radio frequency identification
SCD	Sensing and Controlling Domain
TCP	Transfer Control Protocol
UD	User Domain
UDP	User Datagram Protocol

5 IoT system overview for ecological environment monitoring

5.1 System infrastructure overview

The system infrastructure of the IoT-based ecological environment (i.e. eco-environment) monitoring (EEM) system is described by the Domain-based IoT Reference Model in the IoT Reference Architecture of which the entities are specifically defined for eco-environment monitoring as shown in Figure 1. The system infrastructure of the IoT system of EEM follows the reference architecture of ISO/IEC 30141:2018.

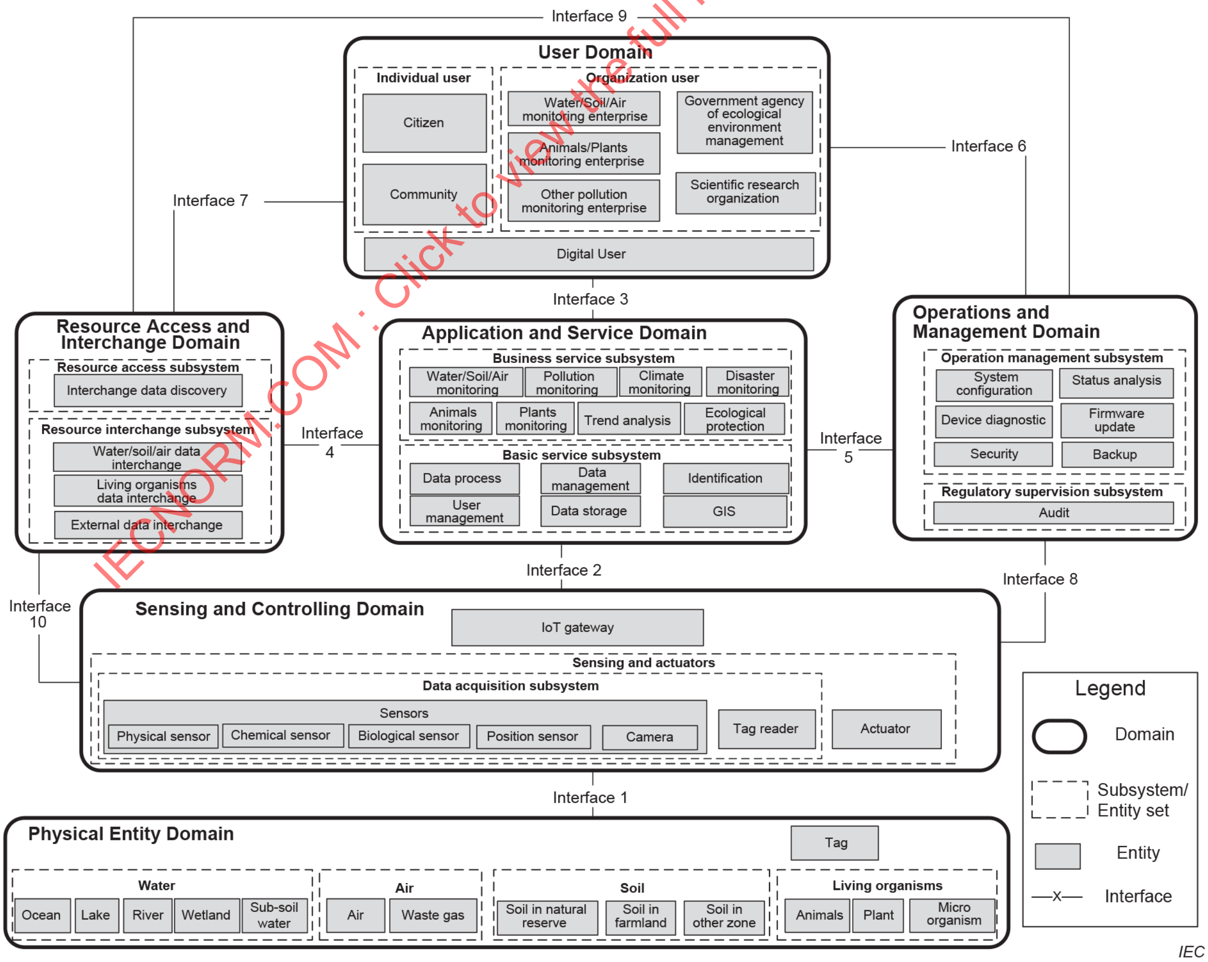

Figure 1 – System infrastructure of IoT system for EEM

5.2 Entities description

5.2.1 Entities in Physical Entity Domain (PED)

The PED mainly consists of the physical objects being sensed by various types of sensors and, for some instances, controlled by certain actuators. Additionally, tags (e.g. barcode, QR code, and RFID) can be attached to some physical objects such as animals and plants. These physical objects are designated as the physical entities which are not only for the IoT-based EEM applications but also are of interest to the users in the User Domain. Typically, four types of physical entities, namely the entity sets, are in the PED, including air, water, soil, and living organisms in grassland, wetland, desert, water body, farmland, city, as shown in Table 1.

Table 1 – Entity descriptions in PED

Entity set	Entity	Entity description
Air	Air	The parameters and quality of air (including temperature, humidity, precipitation and air pressure).
	Waste gas	The component of waste gas (including greenhouse gas).
Water	Ocean	Water quality, salt water body, and acoustic noise and signals.
	Lake	Water quality, immobile fresh water body, and acoustic noise and signals.
	River	Water quality, moving water body, acoustic noise and signals.
	Wetland	Water quality, land area covered or saturated by water.
	Sub-soil water	Water quality, water body immediately below the surface of the soil.
Soil	Soil in natural reserve	The composition, pollution index, geology and other characteristics of soil in the areas of the natural reserve protected by official agency or organization and key areas such as water source zone, tea garden and pasture.
	Soil in farmland	The composition, pollution index, geology, and other characteristics of soil for growing grain, vegetables, fruits, etc.
	Soil in other zone	The composition, pollution index, geology, and other characteristics of soil in other areas such as city, construction areas, pollution accident.
Living organisms	Animals	The growth, activity, living status, and other parameters of all types of animals including water-borne animals, fish, and marine mammals.
	Plant	The growth process and status of all types of plants (e.g. forest.) in grassland, wetland, desert, water body, farmland, city, and also including water-borne plants and planktons (e.g. bacteria, archaea, algae) in water or surface of water body.
	Microorganism	The parameters of the microorganism including the number, type, growth process, status of the microbe or microbes.

5.2.2 Entities in Sensing and Controlling Domain (SCD)

In the SCD, the entities are deployed to collect and integrate data from the PED and receive data from domains through different ways which consist primarily of sensors, actuators, tag readers and IoT gateways.

Sensors acquire information about properties (e.g. physical, chemical, biological properties) of entities of ecosystem. The sensors can be selected according to the required measurement parameter or parameters of the entities in the PED. Actuators[1] can change the local or relevant properties of the entities in the PED in case of emergency or rescue operations. Sensors and actuators can interact with Physical Entities independently or collaboratively. The entity set in the SCD includes sensor, actuator, and tag reader, as described in Figure 1 and Table 2.

IoT gateways are devices which connect SCD with other domains, and they can also connect one entity to another entity in the PED. The IoT gateways provide functions such as protocol conversion, address mapping, data processing for the eco-environment data, information fusion from various eco-environment monitoring sensors in SCD, certification, and equipment management. The IoT gateways can operate either as independent devices or integrated with other sensing and controlling devices. The IoT gateway can also perform security functions for constrained IoT devices – i.e. the IoT devices with limited capability of storage, computing, communication, and power – using the gateway for connectivity to networks. The SCD might also contain local control systems which are used to run control services. Entity descriptions of IoT devices in SCD are described in Table 2.

Table 2 – Entity descriptions in SCD

Entity set	Entity	Entity description
Sensors	Physical sensor	To collect the physical parameters (e.g. temperature, humidity, lighting, acceleration, wavelength of the mechanical movement, or frequency and loudness of acoustic emissions) of ecosystem objects (e.g. air, water, soil, living organisms) and format the raw data for use, transfer, and storage.
	Chemical sensor	To collect the chemical parameters (e.g. gas concentration, composition) of ecosystem objects (e.g. air, water, soil, living organisms) and format the raw data for use, transfer, and storage.
	Biological sensor	To collect the biological parameters (e.g. the number of bacteria) of ecosystem objects (e.g. air, water, soil, living organisms) and format the raw data for use, transfer, and storage
	Position sensor	To collect, compute and form the location data of entities in PED. The format of the location data needs to support three-dimensions and can be the longitude and latitude, elevation coordinates or the relative direction and range from a reference point or an object.
	Camera	To collect multimedia data including audio and video, image of entities in PED and related objects which can then be processed for extracting required information, and be transmitted to data centres.
Actuator	To operate or control or change the associated condition or properties of entities in ecosystem according to the pre-defined condition.	
Tag reader	To collect the data carried by barcodes, QR codes, or RFIDs attached to living organisms (e.g. animals or plants) and obtain the relevant information from them, e.g. to get the type and identity, by scanning the tags attached to the living organisms.	
IoT gateway	To provide the connectivity for the network access or adaptation of the devices with different communication protocols, data aggregation, data analysis, or relay or produce control commands of the sensing and controlling subsystem.	

[1] In the EEM application, the actuators rarely change the properties of the entities in the PED. Actuators cannot change the inherent properties of the air, water, or soil, or living organisms. However, using certain actuators can change the associated condition or properties of the entities.

5.2.3 Entities in Application and Service Domain (ASD)

The purpose of the subsystems in the ASD is to host the core functions, services and applications that deliver the IoT-based EEM to the users (e.g. human or digital entity).

In the ASD, software and hardware systems or subsystems implement not only the basic services but also the business-related services. The ASD's subsystems will provide mainly basic services, including data access, data processing, data fusion, data storage, identification management, geographic information service (GIS), and user management. The ASD's subsystems will also host business-related services and applications required for EEM built on the basic services. The entities in the ASD are described in Table 3.

Table 3 – Entity descriptions in ASD

Entity set or subsystem	Entity	Entity description
Basic service subsystem	Data process	To perform pre-processing, targeted processing, data access, data integration, and data fusion on the data generated from SCD.
	Data management	To manage data resource or database for the ecosystem including, but not limited to, classification, storage, update, data security.
	Identification management	To manage the identity for the ecosystem including the classification, publication, enquiry, maintenance, identity resolution and association, for example the identities of the animals or plants.
	User management	To manage the users in the IoT-based EEM system, including user registration, identity authentication, privilege management, which are also cybersecurity elements.
	Data storage	To store the ecosystem data, for example: the data related to air, water, and soil, the data collected from sensors, and the data obtained from third parties where these data are essential for data processing in the ASD for EEM.
	GIS	To store the geographic information service data, such as geographical map and the maps of ecosystem resource distribution, and other GIS data from third parties that are essential for data processing in the ASD for EEM.
Business service subsystem	Air monitoring	To provide services for air environment management, including air quality management, atmospheric fixed source emission environment management, and noise environment management.
	Water monitoring	To provide services for water environment management, including surface water quality management, drinking water and underground water quality management, waste water management, marine environment management.
	Soil monitoring	To provide services for soil environment management, including soil quality management, soil waste management, chemical management.
	Pollution monitoring	To provide services for pollution source management, including pollution source monitoring, discharge permit management, discharge declaration management.
	Animals monitoring	To provide services for animal management, including animal growth, activity monitoring, condition monitoring, hazard warning.
	Plants monitoring	To provide services for plant management, including plant growth, condition monitoring, hazard warning.
	Climate monitoring	To provide services for climate forecast (e.g. storm, heavy rain).
	Disaster monitoring	To provide services for disaster forecast and early warning, or even emergency response (e.g. large-scale forest fire, earthquake). For example, acquiring the temperature, humidity and smoke concentration of the air in the wide scale of the forest can forecast the forest fire.
	Trends analysis	To analyse the relationships among the physical entities of ecosystem and the changing trends of ecosystem based on ecological element monitoring service.
	Ecological protection	To provide services for nature ecological protection, including soil remediation, biodiversity protection, conservation area management.

5.2.4 Entities in User Domain (UD)

The UD contains both human users and digital users. Digital users are devices of some type, and they interact directly with other entities in the IoT-based EEM system via network interfaces or application programming interfaces. Human users interact using a user interface device, i.e. a human–machine interface (HMI). The HMI subsystem contains the devices and supporting software that allow human users to interact with the EEM system. Depending on the user's role, different aspects of the system will be presented for observation and control. Human users include individual user and organization user, as described in Table 4. Digital user includes devices or the applications installed on the smart phone or smart digital devices, and associated software that processes information to arrive at a conclusion or action.

Table 4 – Entity descriptions in UD

Entity set	Entity	Entity description
Individual user	Citizen	People in the city who use the devices and HMI to access the EEM services for their use, e.g. obtaining the information of the air, water, and soil quality in the city.
	Community	People or social service organizations that use the devices and HMI to access the EEM services for the community, e.g. instant alarming or warning of the eco-environment information when flood or soil erosion happens, or acquiring on-demand information about the eco-environment around the community.
Organization user	Air/Water/Soil monitoring enterprise	Enterprises or institutions that use the equipment and HMI of the EEM services to monitor air, water and soil quality, such as components, contaminants, changing trends, acoustic activity.
	Animals/Plants monitoring enterprise	Enterprises or institutions that use the equipment and outputs of the EEM services to monitor animals and plants, such as activity, location, growth.
	Other pollution monitoring enterprise	Enterprises or institutions that use the equipment and output of the EEM services to monitor discharged constituents of various potential pollution sources including acoustic noise and waste.
	Government agency of eco-environment management	Government agencies that use the equipment and output of the EEM services to monitor, plan, control, and manage the ecological environment.
	Scientific research organization	Scientific research institutes (academic or industry) that use the equipment and HMI of the EEM services to study, analyse, and support decision-making for the ecological environment.
Digital user		Devices or the applications installed on the mornitoring system (e.g. smart phone), or smart digital devices, and associated software that process eco-environment relevant information to arrive at a conclusion or action which is used by the human user.

5.2.5 Entities in Operations and Management Domain (OMD)

The OMD houses the software and hardware systems for the operation monitoring, maintenance and the regulatory compliance supervision of the IoT-based EEM system. The operation monitoring is to ensure the safe and reliable operations of the EEM system. The regulatory supervision is to ensure that the services provided by the EEM system comply with the ecological environment relevant regulations where the EEM system operates. The entities in the OMD are described in Table 5.

Table 5 – Entity descriptions in OMD

Entity set	Entity	Entity description
Operation monitoring subsystem	System configuration	To configure the hardware type, software version, and relevant parameters of the devices for EEM, and update them as the system evolves.
	Status analysis	To collect the operational status of devices for EEM, analyse the data, and alarm in case abnormality is detected.
	Device diagnostic	To predict and locate failures and provide solutions when device is in normal operational conditions.
	Firmware update	To update the software or component over the air or other ways.
	Security	To ensure the physical safety, information confidentiality, network security, privacy protection.
	Backup	To backup the EEM system and its data with a backup and a recovery strategy in order to ensure that the data and services can be restored and operate within a certain period of time after a system failure.
Regulatory supervision subsystem	Audit	To collect the system log files and regulation-relevant data, analyse those data to build a compliance performance of the EEM system, and generate the analysis result and suggestion.

5.2.6 Entities in Resource Access and Interchange Domain (RAID)

The RAID provides the sharing and exchange of information resources between the IoT-based EEM systems and with the external systems such as legacy systems. The RAID includes the software and hardware system entities to realize the exchange of information and services for EEM. The resource access entity manages the resource information access control. The resource interchange entity is to exchange the resource of ecosystem data and relevant external resource. The data exchange method and data format for air, water, or soil is different from living organisms, and air, water, or soil data interchange and living organisms data interchange are described separately in resource interchange. These entities are described in Table 6.

Table 6 – Entity descriptions in RAID

Entity set	Entity	Entity description
Resource access subsystem	Interchange data discovery	To discover resources in order to access the appropriate data from external and internal systems, including air, water, soil, animals, and plants data from the peer IoT EEM systems and other external data from third party systems.
Resource interchange subsystem	Air/Water/Soil data interchange	To exchange data of air, water, or soil ecosystem with external systems, such as the data about distribution, usage, pollution of regional ecosystem to implement analysis, prediction, and control measures.
	Living organisms data interchange	To interchange exchange data of animals, plants, or microorganisms ecosystem with external systems, such as the data about the historical growth of animals to realize analysis and prediction.
	External data interchange	To exchange relevant data of ecosystem with external systems, such as the data about the climate, geometric, population to perform analysis and trend prediction.

5.3 Interface description

Interfaces of IoT-based EEM system are shown in Figure 1, and the interface descriptions in the perspective of information flow are described in Table 7.

Table 7 – Interface description

Interface #	Domain 1	Domain 2	Interface description
IF1	Physical Entity Domain	Sensing and Controlling Domain	The entities in the SCD collect the raw and physical data from the sensors monitoring the ecological environment objects in the PED through this interface.
IF2	Sensing and Controlling Domain	Application and Service Domain	The entities in the ASD acquire the sensor data from the entities in the SCD and send the control commands to the controllers or actuators in the SCD through this interface.
IF3	Application and Service Domain	User Domain	The entities in the UD acquire the specific ecological environment monitoring service from the ASD through this interface.
IF4	Application and Service Domain	Resource Access and Interchange Domain	The entities in the ASD exchange information via the RAID with the peer systems through this interface.
IF5	Application and Service Domain	Operations and Management Domain	The entities in the OMD supervise the system's operational status of the entities in the ASD, and monitor the regulatory aspects of the services provided by the entities in the ASD through this interface.
IF6	User Domain	Operations and Management Domain	The entities in the OMD supervise the system's operational status of the UD through this interface.
IF7	User Domain	Resource Access and Interchange Domain	The entities in the UD exchange information with other peer systems through this interface.
IF8	Sensing and Controlling Domain	Operations and Management Domain	The entities in the OMD supervise the operational status and maintenance information of the entities in the SCD through this interface.
IF9	Operations and Management Domain	Resource Access and Interchange Domain	The entities in the OMD supervise the system's operational status of the RAID, and monitor the regulatory aspects of information exchanges through this interface.
IF10	Sensing and Controlling Domain	Resource Access and Interchange Domain	The entities in the SCD exchange information with other peer systems through this interface; for example, the real-time sensor data is sent out if and only if the sensor data is authorized to be shared with other peer systems.

6 General requirements of IoT system for EEM

6.1 System functional requirements

6.1.1 Data acquisition and data collection

The entities in the ASD should have the ability to acquire sensing data about the eco-environment and transform the sensed data into information. The sensor shall obtain the data, and the IoT gateway shall obtain data from the sensor or sensors and shall transmit it to other domains.

One or more sensors – including physical sensor, chemical sensor, biological sensor, position sensor, camera – shall be used to collect the real-time data for the water, air, soil, and living organisms. The descriptions of entities in the ecosystem monitored by EEM are shown in Table 1. The descriptions of sensors, actuator, tag reader, and IoT gateway used in EEM are shown in Table 2.

The sensors shall be deployed and associated with one or more entities in the ecosystem. The sensors shall not intervene or destroy the natural growing of organisms in the ecosystem. Sensors can be integrated into one to collect multiple types of sensing data, but sensor and integrated sensor shall be equipped with a common interface to transmit data. Tag readers shall be used to collect the data of the plants or animals attached with the tag and their information is stored in the tag.

The typical sensors, which are classified by the types of sensing data they collect, include but are not limited to the following.

- For water quality and water characteristics. Sensors collect the data of water quality, water level, water depth, the amount of water flowing, etc. Other sensor-collected characteristics of water include data of precipitation, evapotranspiration, leakage, runoff, moisture, water potential in the lake, river, sea, etc.
- For air quality and air characteristics. Sensors collect data of air temperature and humidity, air visibility, infrared surface temperature, radiation, air pressure, rainfall, wind speed, wind direction, negative oxygen ions, air particles such as PM2.5 and PM10, etc., some of which are used as the meteorological elements. Sensors for negative oxygen ions typically measure with suction capacitance method, and sensors for the mass concentration of air particles measure with light scattering method.
- For soil quality and soil characteristics. Sensors collect data of soil moisture, soil temperature, soil conductivity, soil water evaporation, soil heat flux, and soil breath which means CO_2 emission rate from soil surface to the atmosphere.
- For living organisms. Sensors collect data of canopy temperature, leaf temperature, stem temperature, leaf condensation, stem sap flow or transpiration, stem diameter, net photosynthetic rate for plants. Sensors collect data of position of the animal, and infrared cameras collect video and image of the animals and ambient environment to extract the number, species, diversity, and habitat of the animals.
- For other ecological environment elements such as noise, flood, snow in the city, rural areas, and wild areas. Sensors collect data of the noise, water level of flood, snow cover, which are used for emergency alarming or meteorological analysis for climate change, global warming, etc. The data of snow cover include snow depth, snow density, snow water equivalent in snow, liquid water content, ice content and other snow characteristics.

6.1.2 Auto configuration

Sensors for eco-environment monitoring should automatically configure the EEM networks and complete service configurations according to a pre-defined network topology and rules.

6.1.3 IoT gateway

IoT gateway shall collect the data from the sensors within the local network, integrate the collected data and send it to other domains. IoT gateway shall manage the local network composed of sensors and convert the local network protocol to other networks' protocols.

6.1.4 Network communication

The network communication shall be required for the entire EEM system. The performance requirements for communication protocols of sensors and IoT gateway are provided in 6.3.6.

6.1.5 Applications and services

Basic service and business service shall be provided for EEM.

For basic service, services of data process, data management, identification management, user management, data storage, and GIS are included.

For business service, services of air monitoring, water monitoring, soil monitoring, animals monitoring, plants monitoring, pollution management, climate monitoring, disaster monitoring, trends analysis and ecological protection are included.

The functional descriptions of each entity in basic service and business service are given in Table 3. Other services can be developed and provided to the users with the development and evolution of EEM.

Services are provided to users who should have the authorized access rights for them, but the services for public users shall be provided openly and shall be easy to access. Services of climate monitoring, disaster monitoring, and trends analysis are provided to public users openly.

6.1.6 Users and supporting facilities

Public user, enterprise user, and government and research user shall access the services with static or interactive interfaces integrated in the facilities including computers, specific devices, smart mobile devices, etc. The descriptions of users are shown in Table 4.

6.1.7 Operation and maintenance management

Operation management and maintenance management shall be provided to make the whole system stable and reliable. For operation management, system configuration, status analysis, device diagnostic, firmware update, security and backup are included. Periodic maintenance of the sensors shall be performed for the sensing data accuracy. Audit shall be supplied for risk management. All the functional entities for operation management and maintenance management are described in Table 5.

The EEM system shall have the ability for operation and maintenance management, including access management, system security management, devices or system operation, and maintenance.

Maintainability requires that upon receiving any system-generated warning message the devices or subsystems shall be repairable or recoverable within a specified time (which differs depending on the device or system) prior to the actual failure.

6.1.8 Context-awareness

Devices and subsystems in the ASD shall have context-aware capabilities. For example, the sensors monitoring for animals should be able to obtain the real-time movement data of the animals in a certain period of time and a certain place, and combine the movement data with metadata such as time, position, weather and other appropriate data in the context to form the animals' state data.

6.1.9 Discoverability

The EEM system should have the ability to discover and access the services in the ASD for users in the UD.

6.1.10 Sharing ability

Within the allowed data security and privacy protection policies, the ecological monitoring data shall be shared with other peer systems having the authorized access rights for the sharing data. For example, sharing data with different types of EEM applications can facilitate the support for remote monitoring and enforcement of a wide eco-environment area.

6.1.11 Resource access and interchange

To guarantee the sharing ability of the system, IoT system for EEM shall provide the resource access and resource interchange. Interchange data discovery shall be supplied for resource access. For resource interchange, water soil and air data interchange, animal and plant data interchange and the third-party data interchange are included. All the functional entities for resource access and interchange are described in Table 6. The data interchange shall be operated with the precondition of security requirements in 6.2.

6.1.12 Identification

Users and devices in the EEM system shall have unique identification, and UUIDs and their use shall be in accordance with ISO/IEC 9834-8:2014. For example, the users can query and track animals' movements or plants' growth through the unique devices attached to animals or plants.

6.1.13 Flexibility

The EEM system should provide a variety of optional services in the ASD according to the needs of users in the UD. For example, services of monitoring optional parameters of water quality, analysis and prediction can be provided, depending on the users' requirements.

6.1.14 Regulation

Users shall be aware of all relevant policies, regulations and laws that can apply to services and operations of the IoT system for EEM and the use of the collected data through the IoT system for EEM.

6.1.15 Equipment, network and service scalability

The equipment, network, and service of the EEM system shall be scalable. The scalability requirement of the EEM system means the system shall continue to function effectively when the number of system entities (e.g. devices, modules, subsystems), networks, or applications and services increases or decreases. For example, when the number of sensors attached to the physical objects (such as animals) increases in a larger area, the network shall still support the data communication of the sensors with other devices or subsystems, and the EEM system shall provide services of monitoring the additional physical objects to which the sensors are attached.

6.1.16 Eco-environment analysis and alarming

The EEM system shall provide alarms upon eco-environment data analysis. According to the eco-environmental quality data obtained at any time and also over a period of time (e.g. historical trend data), the EEM system should perform the analysis of an eco-environmental entity's (air, water, soil, or living organisms) quality trends. If the entity's quality reaches a certain risk level, a warning information or message is generated and sent to users within the required timeline. Actuators shall be activated to respond if possible when the configured threshold condition for EEM is detected.

6.2 System security requirements

6.2.1 Reliability

The ecological monitoring data and services (such as soil environment management, water environment management, pollution source management) provided by the IoT-based EEM system shall be reliable to ensure that the data and services are not tampered with.

Authority and authentication management is needed to configure the different rights to allow the access of data and system functions depending on the identified type of user.

6.2.2 Resilience

The IoT-based EEM system should be resilient. If one IoT gateway fails, other IoT devices in the same network should automatically be configured to temporarily perform as an alternative gateway to prevent the section or entire network from a data transmission interruption between sensing devices and other subsystems.

The system shall provide data backups and have a system restoring capability in case of failure due to natural disaster or human error. To be resilient, the EEM system shall include the following capabilities:

– the devices or subsystem shall have protection function(s) to prevent data loss in case of power failure; and
– the database and application service programs shall be backed up regularly.

6.2.3 Accessibility and availability

The services provided by the EEM system shall be accessible and available to the users depending on the user's approved right and authority for the system.

6.2.4 Confidentiality and privacy

Certain information of water resources, soil resources, national protected animals and plants, and other private information associated with the entities in the PED and their EEM data shall be treated as confidential information. Users shall be aware of policies, regulations, and laws for confidential data in the jurisdiction in which the system is deployed.

EXAMPLE The access and use of these private data in Europe must conform with General Data Protection Regulation (GDPR).

Any data in and from the EEM system shall be encrypted for data confidentiality and privacy prior to storing or transmission.

6.2.5 Integrity

Information about the entities in the PED – for example, water resources, soil resources, national protected animals and plants – and other key EEM data in the EEM system or its database shall be true and accurate, and not be corrupted.

6.3 System performance requirements

6.3.1 Data acquisition sampling rate

The data acquisition sampling rate should define the parameter for the data sampling frequency, i.e. a number of samples per time unit, for each EEM object in the PED. The data acquisition sampling rate should be specified in a time unit, such as per second, minute, hour, or day. The sampling interval depends on the ability of sensing devices, the required sampling rate of EEM applications, network capacity, and other factors. This sampling rate determines the allowed latency of data or timeliness of the system applications, and can also define what "real-time" is for each entity in the PED. Data acquired at different frequency or sample rate shall be handled with suitable and relevant method in such a manner that it will not adversely affect the data accuracy as well as analytics.