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SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Internet of things and smart cities and communities – Services, applications, computation and data processing

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Requirements and capability framework of a digital twin for smart firefighting

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Recommendation ITU-T Y.4601

Requirements and capability framework of a digital twin for smart firefighting

Summary

Recommendation ITU-T Y.4601 specifies the requirements and capability framework of a digital twin for smart firefighting.

A digital twin is a digital representation of an object of interest and may require different capabilities according to the specific domain of application such as synchronization between a physical thing and its digital representation, and real-time support (see Recommendation ITU-T Y.4600).

Through the Internet of things (IoT) technology deployment and the information integration process, a digital twin can provide high fidelity digital representation of a fire scene, enable dynamic convergence between the physical entity and digital entity, achieve comprehensive understanding and control of the past, present and future of the fire scene. The current state of the art for firefighting lacks comprehensive dynamic sensing capability and prediction capability. It cannot provide delayed information, and adequate visibility of the interaction between personnel and a fire scene.

Through the deployment of gateways, sensors, high quality networks, multi-physics simulations, dynamic analysis and predictions and three dimensional (3D) visualizations, the smart firefighting digital twin enables intelligent services such as personnel tracking, hazard tracking, fire scene dynamic analysis, rescue strategy optimization, pre-simulation, historical scene reconstruction, etc. These intelligent services can help to improve decision-making processes and reduce casualties.

History

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FOREWORD

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Requirements and capability framework of a digital twin for smart firefighting

1 Scope

This Recommendation specifies the requirements and capability framework of a digital twin for smart firefighting.

These requirements and capability frameworks build on the IoT reference model [ITU-T Y.4000] and the common requirements of IoT [ITU-T Y.4100]. They focus on the technical aspects of a digital twin for smart firefighting.

The scope of this Recommendation includes:

– Introduction of digital twin for smart firefighting.

– Requirements of digital twin for smart firefighting.

– Capability framework of digital twin for smart firefighting.

Use cases of digital twin for smart firefighting are provided in Appendix.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things*.

[ITU-T Y.4100] Recommendation ITU-T Y.4100/Y.2066 (2014), *Common requirements of the Internet of things.*

[ITU-T Y.4113] Recommendation ITU-T Y.4113 (2016), Requirements of the network for the Internet of things.

[ITU-T Y.4401] Recommendation ITU-T Y.4401/Y.2068 (2015), *Functional framework and capabilities of the Internet of things.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 application [b-ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface.

3.1.2 device [ITU-T Y.4000]: With regard to the Internet of Things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, date capture, data storage and data processing.

3.1.3 digital twin [b-ITU-T Y.4600]: A digital representation of an object of interest.

NOTE – A digital twin may require different capabilities (e.g., synchronization, real-time support) according to the specific domain of application.

3.1.4 gateway [b-ITU-T Y.4101]: A unit in the Internet of Things, which interconnects the devices with the communication networks. It performs the necessary translation between the protocols used in the communication networks and those used by devices.

3.1.5 Internet of things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.6 sensor [b-ITU-T Y.4105]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

3.1.7 thing [ITU-T Y.4000]: In the Internet of Things, object of the physical world (physical things) or of the information world (virtual things), which is capable of being identified and integrated into the communication networks.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 smart firefighting digital twin: A digital twin for support of firefighting intelligent services.

NOTE – A smart firefighting digital twin, providing a digital representation of the previous, current, and future state of the fire scene, enables intelligent services that can help to improve decision-making processes and reduce casualties.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

2D	Two Dimensional
3D	Three Dimensional
CCTV	Closed Circuit Television
EHS	Environment, Health, and Safety
IoT	Internet of Things
NFV	Network Functions Virtualization
PM	Particulate Matter
RSSI	Received Signal Strength Indicator
SDN	Software Defined Network
SSAS	Service Support and Application support
TOA	Time of Arrival

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

The keywords "is recommended" indicate a requirement that is recommended but which is not absolutely required. Thus, this requirement needs not to be present to claim conformance.

The keywords "can optionally" and "may" indicate an optional requirement which is permissible, without implying any sense of being recommended. These terms are not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Introduction of the digital twin for smart firefighting

According to the International Association of Fire Services and Rescue Service (CTIF), World Fire Statistic Report, fire results in 40 thousand deaths and 50 thousand injuries globally every year [b-CTIF-Report-25]. In order to reduce the casualties, the fire department in each country has concentrated on the development of firefighting systems to improve fire fighter safety and the effectiveness of the fire service. However, the state of the art of firefighting technology lacks comprehensive dynamic sensing capability and prediction capability.

The IoT-related firefighting system mainly provides fire protection functionalities (i.e., smoke detector, smart fire extinguisher, escape path instruction message) to reduce the response time and evacuation time. Some smart firefighting technologies provide blueprints or maps of the fire scene, but do not update the status of the fire scene, which changes all the time due to the influence of the fire.

A digital twin can be used to support firefighting intelligent services (smart firefighting).

NOTE 1 – A digital twin is a digital representation of an object of interest and may require different capabilities according to the specific domain of application, such as synchronization between a physical thing and its digital representation, and real-time support [b-ITU-T Y.4600].

A digital twin for smart firefighting utilizes fire scene data to analyse, simulate, and modelling the fire scene, and thus provide a digital representation of the previous, current and future state of the fire scene. It integrates various independent technologies into a comprehensive system. The goal of the digital twin for smart firefighting is to help firefighter enhance situational awareness, understand the fire environment and improve the ability of the fire service. Examples of such services include, but are not limited to, personnel tracking, hazard tracking, fire scene analysis, rescue strategy optimization, pre-simulation, and historical scene reconstruction.

Figure 1 shows the overall conceptual diagram of a digital twin for smart firefighting.

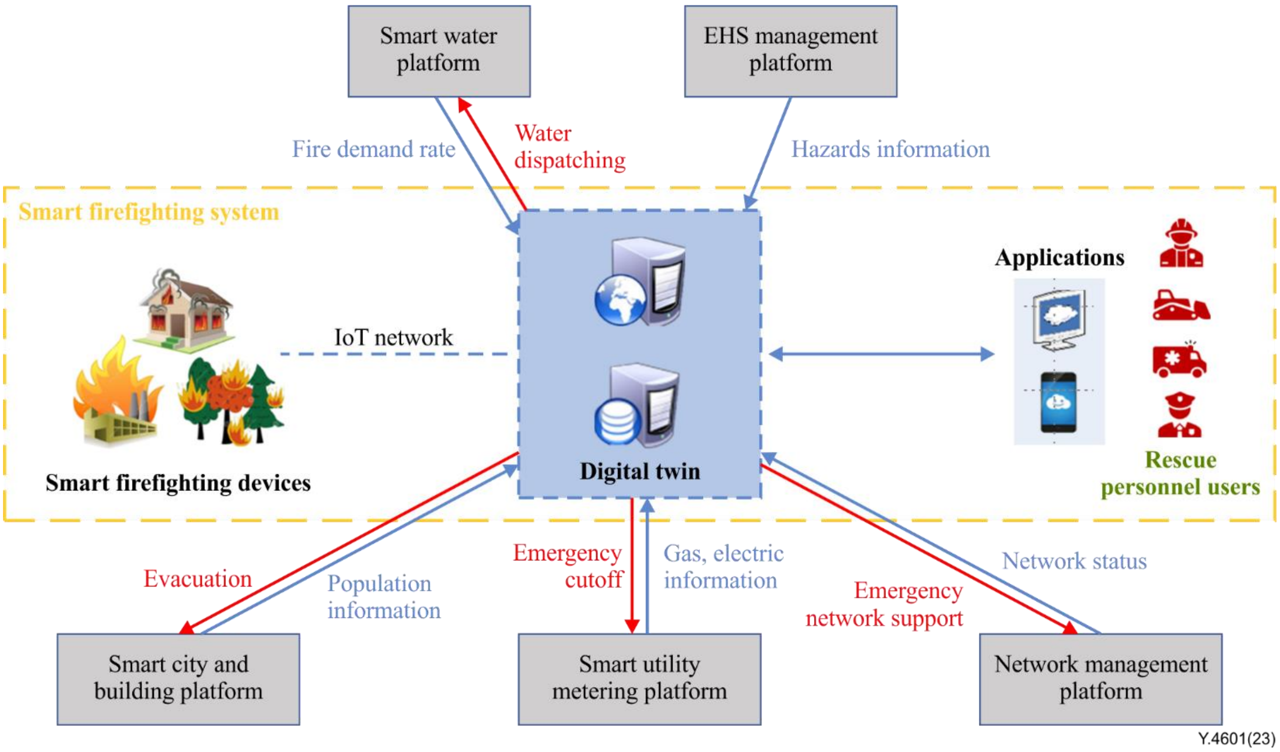

Figure 1 – Overall conceptual diagram of digital twin for smart firefighting

A smart firefighting device consists of environment sensors, rescue personnel sensors, and a gateway for connection to the digital twin. Smart firefighting devices can measure the environmental status, such as temperature, position, O_2/CO_2 concentration and wind speed, as well as rescue personnel vital signs.

NOTE 2 – Rescue personnel may include firefighters, engineers, medical groups and other related personnel.

The network enables the interaction between smart firefighting devices and a firefighting digital twin.

The digital twin component of the smart firefighting system is responsible for collecting and managing environmental data, rescue personnel data and data from other platforms shown in Figure 1. It also performs modelling, visualization, simulation and prediction for purposes of fire scene monitoring and rescue strategy development, and eventually provides fire scene monitoring information, rescue strategy and command to the rescue team.

NOTE 3 – Concerning other platforms, the digital twin may collect information from other platforms such as fire demand rate, hazardous information, population information, gas information and network status, thereby help in developing a rescue strategy. It can also send requests to other platforms for emergency services, such as water dispatching, evacuation, emergency cut-off and emergency network support.

7 Requirements of the smart firefighting system

In addition to the common requirements specified in [ITU-T Y.4000] [ITU-T Y.4100] [ITU-T Y.4113], specific requirements for the smart firefighting system are provided in clauses 7.1 to 7.4.

7.1 Requirements for the devices

The following are the device requirements for the smart firefighting system:

1) General

   – All devices are required to report their status and the collected data to the rescue team mobile devices and the digital twin.

– All devices are recommended to perform self-diagnostic and self-calibration in order to ensure normal operation.

2) Sensor device

– The environmental sensor is required to collect timely information of the fire status, including but not limited to geographical location, temperature, spread direction and fire intensity.

– The environmental sensor is required to collect timely information of the environment, including but not limited to wind, environment temperature and weather.

NOTE – In a burning building, fastmoving spread wind-driven flames, smoke and toxic gases through corridors and stairways can cause casualties without advance notice.

– The environmental sensor is required to collect timely information of the fire consequences, including but not limited to harmful gases (CO_2/CO) concentration, and structural responses (geometric deformation, embrittlement, and meltdown of wood beam, steel beam, brick, forest, etc.).

– The environmental sensor is required to collect timely information of the personnel at the fire scene, such as position, amount, movement data of victims and firefighters. Such technologies include but are not limited to high data rate wireless multimedia networks technology [b-IEEE 802.15.3], low rate wireless networks technology [b-IEEE 802.15.4] and monitoring camera.

– The environmental sensor is required to be spread over in order to cover the whole environment.

– The personnel sensor is required to collect timely information of firefighters, such as vital signs (blood oxygen level, blood CO level, heartbeat, respiration and body temperature), position and the surrounding environmental parameters that are related to the firefighters' health.

– Sensors are required to transmit timely sensing information to all firefighters and dispatching centres.

– Sensors are recommended to provide false alarm filtering functionality.

3) Mobile device

– The mobile device is required to support multiple input interfaces, such as physical button input and automatic speech recognition.

– The mobile device is required to support video / image display, data storage, networking, three-dimensional (3D) model representation, application download, and update functionalities.

4) Gateway device

– The gateway device is required to support or connect to an isolated network. The gateway device can optionally support network slicing or employ physical separation to avoid any interference from the public network.

7.2 Requirements for the network

The following are the network requirements for the smart firefighting system:

1) The network is required to remain isolated from the public network. The support of physical isolation technology is recommended, while network slicing technology can be optionally supported. Examples of network slicing technology include but are not limited to a software defined network (SDN) [b-SD-RAN V1.0] and network function visualization (NFV) [b-ETSI GS NFV 002]. Examples of physical isolation technology include, but are not limited to, air-gap [b-DiFazio], application-level gateway [b-NEXTEP] and circuit-level gateway [b-NEXTEP].

2) The network is required to provide the location related information, such as received signal strength indicator (RSSI), time of arrival (TOA), frequency shift and phase shift, which can be used for device position computation [b-Telink].

7.3 Requirements for the digital twin

The following are the requirements for the digital twin component of the smart firefighting system:

1) General

   – It is required to locate each device and link it to its real-time status.

     NOTE – For instance, the digital twin component monitors the position of firefighters and notifies them when they are near a dangerous area or a potential risk.

   – It is required to support indoor and outdoor navigation and positioning.

   – It is required to monitor the health conditions of firefighters and notify them when their vital signs are near the critical thresholds.

   – It is required to store all information and models in a secured local database and update a copy to a remote location.

   – It is required to store information of the past fire scene for future rehearsals.

   – It is required to share fire scene and dispatch information to involved personnel in order to help additional supporting teams to understand the situation, such as the police, the engineering group, and the medical aid.

   – It is required to share fire scene and dispatch information with other smart platforms in order to perform emergency cut-off or dispatching.

   – It is required to provide data pre-processing before modelling and simulation, such pre-processing includes but is not limited to data cleaning, data mining and data analysis.

2) Multi-physics modelling

   – It is required to support the modelling of the architecture, topography, and/or structure of the environment.

   – It is required to support the modelling of the chemical and physical properties of hazards (flammable, combustible, toxic, etc.).

   – It is required to support the modelling of various properties of the environment such as geometry, weight, structure and the physical and chemical properties of the materials.

   – It is required to support the modelling of the firefighter equipment and their working mechanism.

   – It is recommended to perform scene rendering, providing fire scene visualization for the rescue and supporting team.

3) Multi-physics simulation

   – It is required to support the analytical simulation of the current fire scene based on the sensing data.

   – It is required to predict the evolution of the fire scene based on the sensing data; such predictions include but are not limited to structural response, fire intensity, fire spreading direction, and spreading rate.

   – It is required to support the simulation of the rescue strategy optimization.

   – It is required to support a simulation space to create different virtual fire scenes.

4) Visualization

   – It is required to support the visualization of the architecture, topography or structure of the environment in 3D and two dimensional (2D) modes.

– It is required to support the visualization of all personnel, device, equipment, hazard, and environment in the fire scene through a graphical user interface.
– It is required to support the visualization of the status of the personnel, equipment, devices, hazard, and environment at the fire scene.
– It is required to support the visualization of the physical interaction between objects and the (current and predicted) environment.
– It is required to support the visualization of the indoor and outdoor navigation and positioning.
– It is required to support the visualization of the strategy optimization.
– It is required to support the visualization of the impact on strategy change.

7.4 Requirements for the applications

The following are the application requirements for the smart firefighting system:

– The applications are required to support multiple input/output modes which can contribute to minimize the number of steps to operate them.
– The applications are required to support multiple communication modes which can facilitate communication among the relevant rescue personnel.

8 Capability framework for the smart firefighting system

Based on the IoT reference model specified in [ITU-T Y.4000], Figure 2 illustrates the capability framework of the smart firefighting system, which consists of four layers and two cross-layer capability groups. In addition to the common capabilities of IoT specified in [ITU-T Y.4401], additional or enhanced capabilities are required for the smart firefighting system, as shown via rectangles with solid lines in Figure 2.

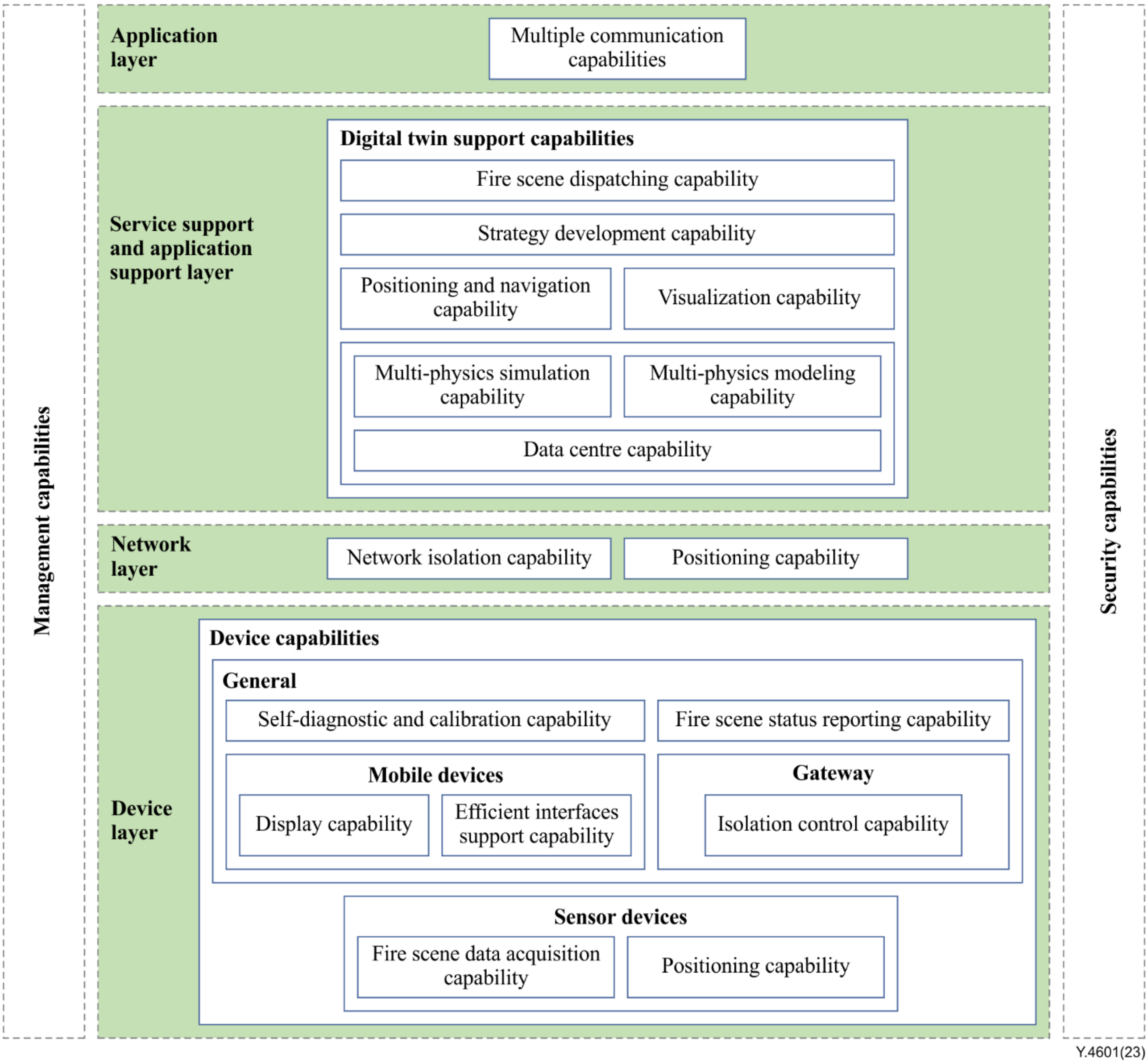

Figure 2 – Capability framework of the smart firefighting system

The following clauses describe the specific capabilities of a smart firefighting system.

8.1 Capabilities of the device layer

8.1.1 General

1) Self-diagnostic and calibration capability

According to the requirements of clause 7.1.(1), self-diagnostic and calibration capability ensures the normal operation and function of the devices, including but not limited to:

– Performing self-diagnostics and self-calibration based on the pre-stored algorithm or invoking support from the service support and application support (SSAS) layer.

– Performing self-calibration automatically and periodically based on the pre-stored reference and configuration when an abnormal data is detected.

– Performing self-diagnostics automatically and periodically analysing the working status of the devices and detecting abnormal data.

2) Fire scene status reporting capability

According to the requirements of clause 7.1.(1), the fire scene status reporting capability reports the essential data to other capabilities to help users understand the status of the devices, including but not limited to:

– Enabling devices to report the fire scene data to the digital twin support capability and to rescue team mobile devices.

– Enabling devices to report the fire scene malfunction information and calibration result to the data centre capability.

8.1.2 Sensor device

1) Fire scene data acquisition capability

According to the requirements of clause 7.1.(2), the fire scene data acquisition capabilities enable the sensor devices to monitor and collect fire scene information, including but not limited to:

– Collecting fire scene information related to the environment, such as the wind speed, wind direction, environment temperature, and weather.

– Collecting fire scene information related to the fire status, such as the static and dynamic temperature distribution, flame length, and the energy released from the fire.

– Collecting fire scene information related to fire effects, such as the concentration of harmful gases (CO_2/CO/hydrogen cyanide), and structural responses from tilt sensing, pressure sensing, strain dynamic sensing, vibration sensing, temperature sensing, magnetic flux sensing, etc.

– Collecting fire scene information related to the rescue strategy effects, such as particulate matter (PM) concentration, breach, and humidity.

– Collecting the fire scene information related to the rescue teams' vital signs, such as blood oxygen, blood CO, heartbeat, respiration and body temperature.

2) Positioning capability

According to the requirements of clause 7.1.(2), the positioning capability enables the sensor devices to detect positions and motions based on the physical principles and pre-stored coordinates from the data centre capability. Such devices include but are not limited to the closed circuit television (CCTV), pressure sensors, ultrasonic proximity sensors and inertial reference.

3) False-alarm filtering capability

According to the requirements of clause 7.1.(2), the false-alarm filtering capability enables the sensor devices to purposefully delay the fire alarm before the fire status is verified.

NOTE – When an abnormality is detected, the sensor devices communicate with the surrounding sensors to confirm the truthfulness of the fire alarm. If the fire is confirmed in the device layer, it will trigger a fire alarm immediately, otherwise sensors are required to send the fire alarm log, self-diagnostic result, self-calibration result, and data of surrounding sensors to the digital twin platform for a second check.

8.1.3 Mobile device

1) Display capability

According to the requirements of clause 7.1.(3), the display capability enables the firefighters' mobile devices to display the information in the text, audio, image or video format.

2) Efficient interfaces support capability

According to the requirements of clause 7.1.(3), the efficient interfaces support capability enables rescue teams to efficiently interact with each other and with the smart firefighting system, including but not limited to:

– Voice input / output support.

– Image and video input support.

– Physical button input support.

8.1.4 Gateway

1) Isolation control capability

According to the requirements of clause 7.1.(4), the isolation control capability enables gateways to support network isolation technologies. Such technologies include network slicing, packet filter and different types of firewalls.

8.2 Capabilities of the network layer

1) Network isolation capability

According to the requirements of clause 7.1.(1), the network isolation capability enables the networks to be isolated from the public network, such methods include, but are not limited to, network-level firewall, virtual switches, VLAN and physical isolation.

2) Positioning capability

According to the requirements of clause 7.1.(2), the positioning capability enables the network to use proper data transmission format and signal conditioning to report access point information to the digital twin support capability, such as location, frequency, signal arrival time and received signal strength indicator (RSSI).

NOTE – The positioning capability normally uses three or more known access points as anchor nodes, and then employs a positioning method to compute the precise location.

8.3 Capabilities of the service support and application support layer

1) Data centre capability

According to the requirements of clause 7.1.(2), the data centre capability monitors the data among different capabilities of devices, networks and applications, and provides data processing before further modelling or simulation. The data centre capability includes, but is not limited to:

– Monitoring the real-time working status and configuration of the devices and network.

– Monitoring the environment data from sensors.

– Collecting data from other connected platforms or servers.

– Sending commands to other connected platforms or servers for emergency services support.

– Providing data conditioning for raw data and validation for data accuracy.

2) Multi-physics simulation capability

According to the requirements of clause 7.3.(3), the multi-physics simulation capability analyses the fire scene data based on the mathematical simulation of physical and/or chemical interactions. Such capability includes but is not limited to:

– Processing the collected data with the support of statistics and probability equations.

– Processing the collected data with physical and/or chemical models and theories, such as thermal dynamics, aerodynamics, mechanics, toxicology, human physiology, chemistry, and material science.

– Processing the collected data with mathematics to simulate the interactions among the effects of real forces. Such capability includes but is not limited to the finite element analysis and the density functional theory.

3) Multi-physics modelling capability

According to the requirements of clause 7.3.(2), the multi-physics modelling capability enables the smart firefighting digital twin support capability to build up models of current fire scenes, historical fire scenes and predicated fire scenes, including but not limited to:

– Constructing descriptive 2D/3D models of personnel, equipment, devices, and environmental structures in the fire scenes, such as geometry, location and shape of the objects.

– Constructing physical and/or chemical 3D models of personnel, equipment, devices and environment, which is linked with the principles and mechanisms, such as physical and chemical properties of the materials.

4) Visualization capability

According to the requirements of clause 7.3.(4), the visualization capability enables the digital twin support capability to visualize models, data and simulation results, including but not limited to:

– Visualizing the properties of the fire scene.

– Visualizing the properties of the objects and personnel in the fire scene.

– Visualizing the simulation result in a basic presentation to enhance the interpretation of complex systems and data sets.

– Visualizing the consequence of the rescue strategy.

– Visualizing the movement of the rescue team and victims at the fire scene.

5) Positioning and navigation capability

According to the requirements of clause 7.3.(1), the positioning and navigation capability enables the digital twin support capability to monitor the location and motion of the objects, and support navigation guidance, including but not limited to:

– Requesting the location information of personnel, device, fire, hazard and equipment, and tracking the real-time position.

– Providing navigation guidance to the rescue team based on the predicated fire scene results.

– Planning and searching for the optimal route (with respect to time and safety) based on the real-time fire scene status.

6) Strategy development capability

According to the requirements of clause 7.3.(1), the strategy development capability develops and optimizes rescue strategies, including but not limited to:

– Developing rescue strategies such as rescue entrance, rescue exit, rescue sequence, carried equipment to minimize the casualties.

– Analyzing the possible consequences of developed rescue strategies.

– Sorting developed rescue strategies based on the predicted consequences, such as time consumption, possible casualties, assets loss and success rate, and selecting optimal strategies according to the requirements.

– Combining optimal parameters of predicted consequences and historical rescue strategies to optimize the rescue strategy.

7) Fire scene dispatching capability

According to the requirements of clause 7.3.(2), the fire scene dispatching capability dispatches the data, instructions and commands to devices and relevant personnel, including but not limited to:

– Dispatching position information, environment data and firefighters' vital signs to the rescue team.

– Dispatching alarms when the rescue team is approaching a hazardous environment or a potentially hazardous environment.
– Dispatching alarms when the vital signs of the rescue team are near a critical threshold.
– Dispatching commands and strategy to the rescue team along with the highest possible result that is predicated by the multi-physics simulation.
– Dispatching requests to other connected platforms in due course, in order to issue instructions according to the fire status.

8.4 Capabilities of applications

1) Multiple communication capabilities

According to the requirements of clause 7.4, the multiple communication capabilities enable the rescue team members to communicate with each other and the digital twin support platform in multiple ways, including but not limited to:

– Support of automatic speech recognition.
– Support of selective calls, group calls, broadcasting among rescue team members and to the digital twin support platform.

Appendix I

Use cases of digital twin for smart firefighting

(This appendix does not form an integral part of this Recommendation.)

I.1 Fire scene monitoring

When a fire occurs, the smart firefighting digital twin uses the sensors and the network to collect environmental and position information. Then the platform invokes prestored architecture or a topology model to visualize the environmental and position information on the model. Thus, the model intuitively reflects the real-time status of the fire scene.

As shown in Figure I.1, the portable sensor is responsible for collecting the location, vital signs and surrounding environmental information of the rescue team; the fixed sensor is responsible for collecting the information of the hazardous gases, temperatures, smoke, structures in the environment, and the position of the surrounding personnel. The information is then transmitted to the smart firefighting digital twin through the network. The digital twin then maps the environmental and personnel information to the prestored architecture or topology model to visualize the fire scene. In this way, the fire department and rescue team become aware of the situation at the fire scene.

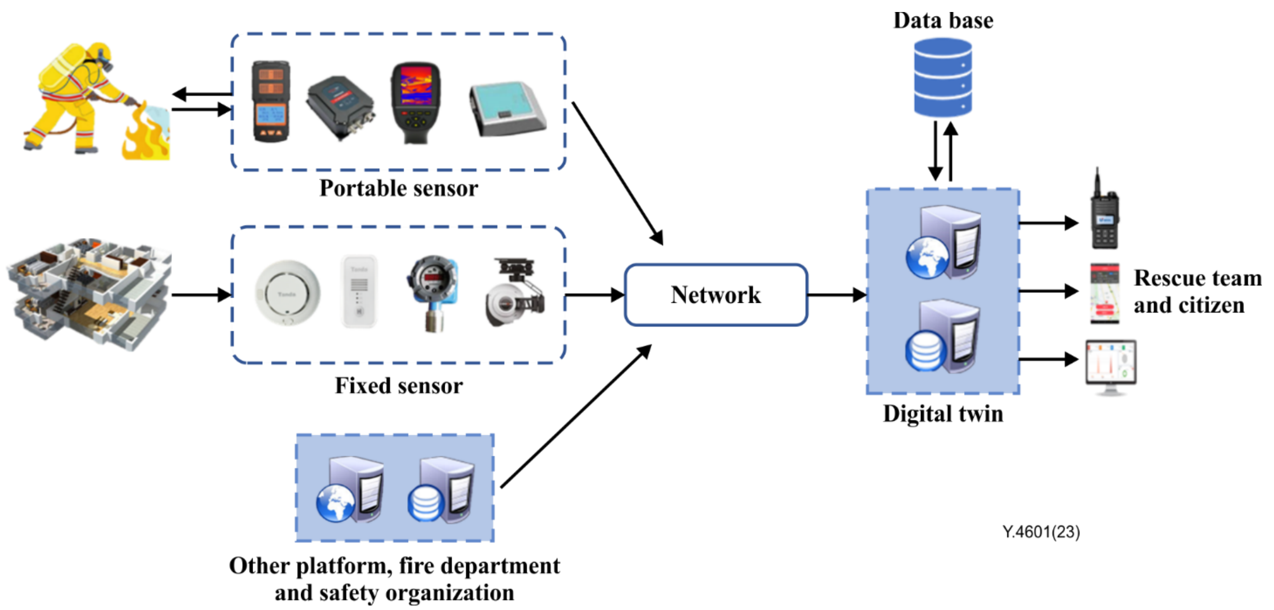

Figure I.1 – Fire scene monitoring

I.2 Rescue strategy development and training

As shown in Figure I.2, after the digital twin has acquired the fire scene information, it maps all information to the prestored environment model for the fire scene monitoring. The digital twin uses multi-physics modelling and simulation with prestored environment material properties to construct a virtual scene of the occurrence of fire incidents, where the simulation provides a report on the influence of the fire incidents or other hazards to the rescue personnel in the fire scene.

The digital twin also provides a prediction of the fire scene evolution for the rescue people to help them avoid potential risks caused by the topography or structural change in the fire. As shown in the dashed box of Figure I.2, as an example, the simulation may predict that the fire will spread to the other three floors in one hour, and the left building will have higher fire intensity: this prediction can then notify potential risks and rescue time limit to the rescue team. The digital twin can then develop a rescue strategy based on the real-time simulation and future predication: the digital twin can develop multiple strategies, but only send the best and second-best strategies to the rescue team based on the comprehensive evaluation of time consumption, possible casualties, assets loss and success rate.

The simulation can also be used in training to offer trainees experience in incident situations in a safe, contained, repeatable, controllable and measurable environment, which is of great practical significance. The simulation is based on the data of historical fire scenes and realistic potential scenes.

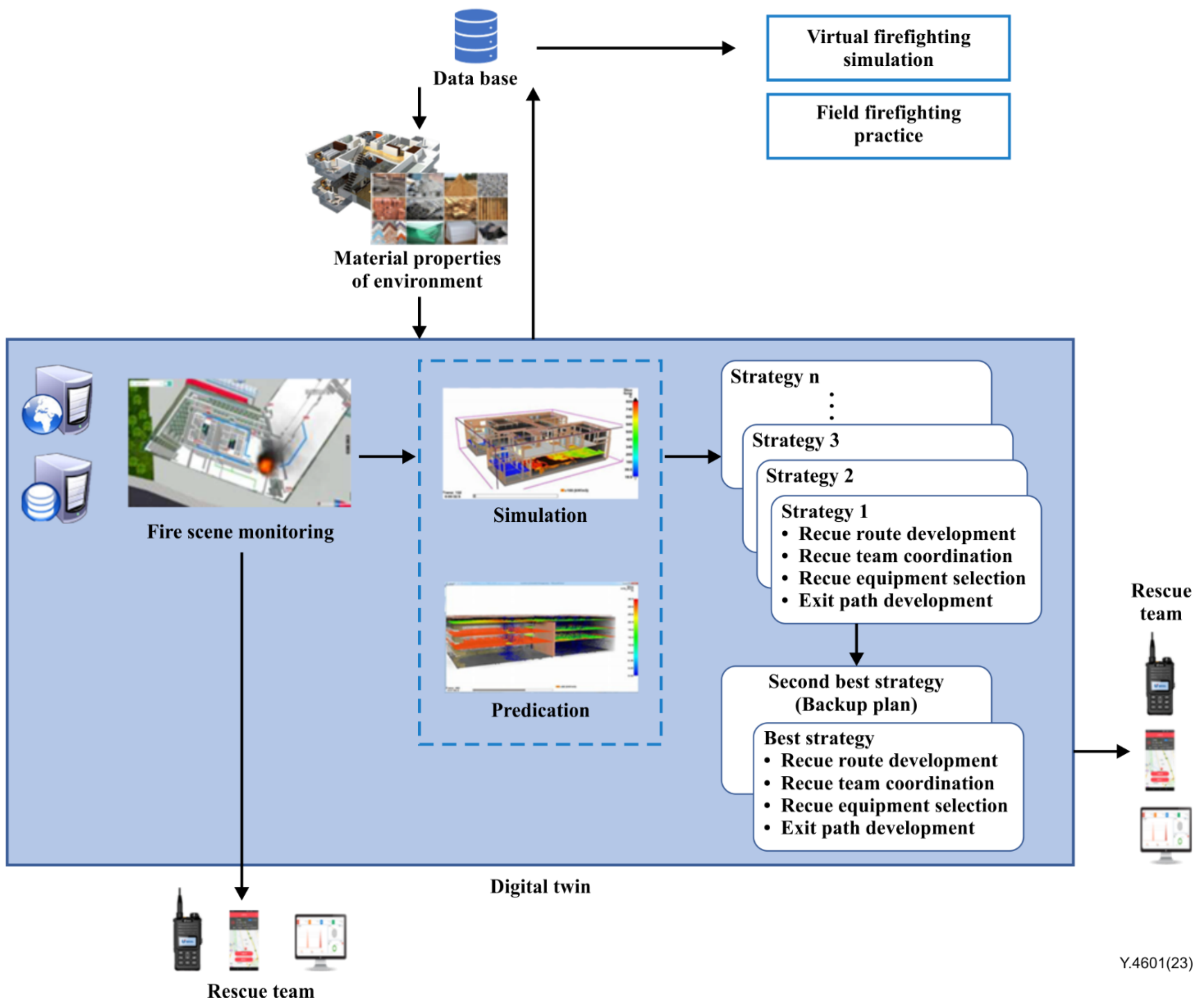

Figure I.2 – Rescue strategy development and training

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