ISO/IEC TR 30164

Edition 1.0 2020-04

TECHNICAL REPORT

Internet of things (IoT) – Edge computing

colour inside

ISO/IEC TR 30164:2020-04(en)

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Internet of things (IoT) – Edge computing

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 35.020

ISBN 978-2-8322-8087-4

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INTERNET OF THINGS (IoT) – EDGE COMPUTING

FOREWORD

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ISO/IEC TR 30164, which is a Technical Report, has been prepared by subcommittee 41: Internet of Things and related technologies, of ISO/IEC joint technical committee 1: Information technology.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
JTC1-SC41/110/DTR	JTC1-SC41/120/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTERNET OF THINGS (IoT) – EDGE COMPUTING

1 Scope

This document describes the common concepts, terminologies, characteristics, use cases and technologies (including data management, coordination, processing, network functionality, heterogeneous computing, security, hardware/software optimization) of edge computing for IoT systems applications. This document is also meant to assist in the identification of potential areas for standardization in edge computing for IoT.

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 20924, *Internet of Things (IoT) – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 20924 and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
edge
boundary between pertinent digital and physical entities, delineated by networked sensors and actuators

3.2
edge computing
distributed computing that takes place at or near the edge, where the nearness is defined by the system's requirements

3.3
software defined network
SDN
network designed, built and managed with separation of the control plane from the forwarding plane and abstraction of the underlying infrastructure, enabling efficient network management and utilization

3.4
personally identifiable information
PII
information that (a) can be used to establish a link between the information and the natural person to whom such information relates, or (b) is or can be directly or indirectly linked to a natural person

[SOURCE: ISO/IEC 29100:2011 [1], 2.9, modified – In the definition, "to identify the PII principal" has been replaced by "to establish a link between the information and the natural person" and "a PII principal" has been replaced by "a natural person".]

3.5
edge computing entity
ECE
thing (physical or non-physical) having a distinct existence in an edge computing system, with connection, storage and computation capabilities

Note 1 to entry: ISO/IEC TR 23188:2020 [2] uses the term "edge computing node" instead of "edge computing entity".

3.6
distributed computing
model of computing in which processing and storage takes place on a set of entities, with activities coordinated by means of digital messages passed between the entities

3.7
physical edge computing entity
edge computing entity that has material existence in the physical world

EXAMPLES: IoT gateway, sensor, actuator

Note 1 to entry: Refer to ISO/IEC 20924 [3] for the definitions of the terms "sensor", "actuator" and "IoT gateway".

3.8
IoT gateway
edge computing entity that connects one or more proximity networks and the edge devices on those networks to each other and to one or more access networks

3.9
edge computing system
system that uses the structure and capabilities of edge computing

4 Abbreviated terms

4G	the fourth generation of broadband cellular network technology
5G	the fifth generation of broadband cellular network technology
AI	artificial intelligence
AMQP	advanced message queuing protocol
API	application programming interface
APP	applications
CAN	controller area network
CPS	cyber physical system
CPU	central processing unit
CT	communication technology
DDoS	distributed denial-of-service
DDS	data distribution service
DER	distributed energy resource
DetNet	deterministic networking
ECE	edge computing entity
ERP	enterprise resource planning
GEO	geosynchronous orbit

GPS	global positioning system
GPU	graphics processing unit
HSA	heterogeneous system architecture
HTTPS	hypertext transfer protocol secure
I/O	input/output
ICT	information and communication technology
IDS	intrusion detection systems
IEC	International Electrotechnical Commission
IIoT	industrial IoT
IoT	Internet of Things
IP	internet protocol
IPS	intrusion prevention systems
ISO	International Organization for Standardization
IT	information technology
JSON	JavaScript Object Notation
JTC	joint technical committee
LEO	low earth orbit,
LAN	local area network
LiDAR	light detection and ranging
M2M	machine to machine
MEO	medium earth orbit
MES	manufacturing execution system
MPLS	multiprotocol label switching
O&M	operation and management
OPC	open platform communication
OPC-UA	OPC unified architecture
OS	operating system
OT	operational technology
PII	personally identifiable information
PLC	programmable logic controller
PLM	product lifecycle management
PO	purchase order
PV	photovoltaic
QoS	quality of service
REST	representational state transfer
SC	subcommittee
SCADA	supervisory control and data acquisition
SDN	software defined networking
TCP	transmission control protocol
TLS	transport layer security
TR	Technical Report
TSN	time sensitive networking
UDP	user datagram protocol

V2I	vehicle to infrastructure
V2V	vehicle to vehicle
VM	virtual machine
VNF	virtualized network function
VPN	virtual private network
VPP	virtual power plant
WAF	web application firewall
XML	extensible markup language

5 Overview

5.1 General

This document was jointly developed by the teams working on ISO/IEC TR 23188 [2] with cloud computing perspectives and ISO/IEC TR 30164 with IoT computing perspectives. The separate documents exist to expand on these particular perspectives starting from a common base of edge computing concepts, which are stated below. ISO/IEC TR 23188 [2] provides more information on how cloud computing relates to edge computing. ISO/IEC TR 30164 provides more information on how IoT devices and IoT systems relate to edge computing.

5.2 Common concepts

Edge computing is a form of distributed computing in which processing and storage takes place on a set of networked machines which are near the edge, where the nearness is defined by the system's requirements. The edge is marked by the boundary between pertinent digital and physical entities (i.e. between the digital system and the physical world) typically delineated by IoT devices and end-user devices. Nearness is determined by the system requirements, which can include physical distance, but can also include digital factors such as network latency and bandwidth.

Pertinent digital entities here means that the digital entities which need to be considered can vary depending on the system under consideration and the context in which those entities are used.

Digital systems can observe and affect the physical world. Sensors, actuators and human user interface devices are at the boundary between the physical world and digital systems (the edge). Edge computing systems generally combine these devices with distributed computing resources to provide the capabilities of the system. When actions need to occur within specific timeframes and latency considerations affect system design, the edge computing systems help to achieve timing requirements by means of appropriate placement of data processing and data storage. The following are the main motivations for edge computing.

a) Latency: actions often need to occur within specific timeframes and latency considerations affect system design and the choice of the placement of data processing and data storage to achieve timing requirements.

b) Disconnected operations: for example, a car in a canyon. All essential functions need to continue to work.

c) Paucity or high cost of the uplink: for example, an oil rig, a cruise ship or an airliner connected via a satellite link. Need to minimize the volume of data transmitted upstream.

d) Data providence: for example, data represents trade secrets and should not leave a geofence (factory space or corporate network).

Edge computing is characterized by networked systems in which significant data processing and data storage takes place on entities at the edge, rather than in some centralized location. Edge computing can be contrasted with centralized computing where the centralized entities are remote from the edge. However, it is important to note that edge computing is complementary to centralized forms of computing and that in any given system, edge computing is often used in conjunction with centralized computing.

An example of the need to consider the context for the meaning of edge is the servers within a cloud data centre. From the perspective of cloud service customers who build systems using cloud services running on these servers, these entities are anything but at the edge – they are highly centralized. However, from the perspective of the cloud service provider having to manage the cloud data centre, it is highly likely that the servers are instrumented with a variety of IoT sensors capable of reporting various physical properties of the servers, for example, their temperature. In this case, those IoT sensors are at the edge and form part of an edge computing system for managing the data centre.

Edge computing involves entities that are highly heterogeneous and which are commonly arranged in tiers of compute and storage capabilities. The multiple edge computing tiers, each containing varying types of entities, are connected by networks which can also vary in nature depending on the tiers involved. In practice, the number of tiers and the type of entity in each tier is variable, depending on the nature of the system involved.

1) The device tier is at the edge. It typically contains entities which contain sensors or actuators or human user interface devices. Such devices often have limited compute and storage capabilities. The networks used by this tier are often proximity networks, with limited bandwidth and limited range.
2) The edge tier typically sits close to the device tier and its role is to provide direct support to the entities in the device tier. One type of entity in the gateway tier is the gateway (an IoT gateway is an example). The role of the gateway is to connect entities in the device tier to the wider network – it is often the case that proximity networks are local and cannot be used for communication over a wide area. The gateway also typically provides a means for managing the entities in the device tier.
3) Another type of entity in the gateway tier is the control entity. The control entity receives data from entities in the device tier – typically data from sensors or input from user interface devices – and responds by issuing instructions to other entities in the device tier, based on control software running in the control entity. Control entities are usually placed in the gateway tier due to issues of latency and timing. The response of a control entity is often time constrained (sometimes called real-time), such that the response needs to be given before some deadline following the receipt of some data or an event.
4) The central tier represents a tier of entities provided in a centralized location, such as an organizational data centre or as public cloud services. The entities in the central tier offer the ability to provide very substantial compute power and data storage (sometimes termed "unlimited"). The central tier is an excellent place to conduct analytics or other processing that requires both a lot of compute power and also access to a lot of information. The central tier can hold large stores of information which can come from many sources – this may be from across the other tiers of the system or from outside locations, potentially sourced from other organizations.

5.3 General concepts of edge computing

When observing and affecting the physical world, sensors and actuators are at the boundary of the physical world and cyber systems. IoT systems generally use distributed computing resources, combined with sensors and actuators, to enable these interactions (i.e. observing and affecting the physical world). Typical solutions in this area have requirements that actions need to be completed within specific timeframes following some event or observation. Therefore, an awareness of the latency between IoT entities (the computing resources, sensors, and actuators) is needed to achieve those timing requirements. Edge computing helps meet those timing requirements. Edge computing is characterized by networked systems ("connection") in which significant data processing ("compute") and information storage ("storage") take place on devices and entities near the edge, rather than in some centralized location. Edge computing provides the system with reduced latency bounds, beneficial to network and computation, potentially leading to efficiency gains for each. Edge computing can be contrasted with centralized computing (for example, a large cloud computing data centre), where the resources are centralized in large remote data centres. However, it is important to note that edge computing is complementary to centralized forms of computing and that in any given system, edge computing is typically used in conjunction with these centralized computing resources.

A significant driver for the increasing use of edge computing is the continuing increase in the processing power and in the data storage capacities of small and low-power devices and systems that can be placed in locations away from traditional data centres, to address the increasing need to process data quickly in response to input from a sensor. The evolution of mobile phones with their high processing power and large data storage capacity in a small and low-power package has undoubtedly been one of the driving forces in this evolution. However, it is also increasingly the case that innovative IoT systems are driving the requirements for more powerful low-power devices, including the evolution of newer forms of devices such as wearables, robots, and large scale distributed sensor networks.

Edge computing serves a need where actuators are affecting the real world – and there is a need for rapid and close control over those actuators. Edge computing can also serve the needs of human users in remote locations – providing them with a user interface and associated applications that enable them to accomplish tasks and activities. Edge computing can deal with situations where substantial volumes of data are being generated at edge locations and where it is impractical or too costly to transmit all that data to a central location for processing – an example of this is where a set of cameras are providing video feeds. It may be possible to perform a substantial amount of processing at the edge and only transmit a much smaller amount of processed data to a central location (e.g. a count of people in a scene). In other cases, data security can be increased by not transferring data to other locations. By extension, device security, connection security, data security, application security and data privacy could be improved by constraining the data and system to a local region.

An example networking table is shown in Table 1.

Table 1 – Example networking table

Technology	Approximate transmission speed	Approximate latency (single hop)
Wired / Ethernet	100 Mbit/s to 10 Gbit/s	0,3 ms
Cellular/2G/3G/4G/5G	3G – 2 Mbit/s 4G – 20 Mbit/s 5G – 10 Gbit/s	3G – 100 ms 4G – 50 ms 5G – 1 ms
Wi-Fi® [a]	54 Mbit/s theoretical for 802.11n	3 ms
Power line communications	100 Mbit/s	10 ms
Low power, long-range wireless	100 bit/s to 300 kbit/s	1 s to 10 s
Satellite communication: low earth orbit (LEO), medium earth orbit (MEO), geosynchronous orbit (GEO)	LEO: kbit/s to Mbit/s (depending upon system and application) MEO: kbit/s to Mbit/s (depending upon system and application) GEO: kbit/s to Mbit/s (depending upon system and application)	LEO: > 10 ms transmission delay MEO: > 100 ms transmission delay GEO: > 250 ms transmission delay

[a] Wi-Fi is a registered trademark of Wi-Fi Alliance. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC or ISO.

Capabilities of some IoT entities are shown in Table 2.

Table 2 – Capabilities of some IoT entities

Device category	Data consumed	Data generated
Sensing	Application specific – may vary from very small to very large amounts of data.	Application specific – may vary from very small to very large amounts of data.
Actuating	Application specific – may vary from very small to very large amounts of data.	Application specific – may vary from very small to very large amounts of data.
Processing	Application specific – may vary from very small to very large amounts of data.	Application specific – may vary from very small to very large amounts of data.
Data storing	Application specific – may vary from very small to very large amounts of data.	Application specific – may vary from very small to very large amounts of data.

Edge entities vary widely in their compute, storage, networking and data acquisition capabilities. They range from an embedded system, a Raspberry Pi™ [1] grade device to a full PC and micro data centre. A partial example classification is as follows.

- Light compute, light data entities, with very limited compute power and limited data generation.

  Such entities are typically optimized for low cost and low power consumption. Devices commonly have embedded firmware and a very limited operating system (or none at all). They are oriented towards fixed-function capabilities. Communication capabilities may take the form of a low-power, limited reach proximity network of some kind.

- Light compute, heavy data entities, with limited compute power and substantial data generation.

  Such entities generate or deliver substantial data, typically need high bandwidth with other edge devices within the network.

- Heavy compute, light data entities, with substantial compute power, but limited data generation.

  Such entities can have complex processing logics and process data locally. Limited data is delivered to other edge devices through simple and standardized APIs.

- Heavy compute, heavy data entities, with substantial compute power and substantial data generation.

  These are typically full-blown computer systems, although they may be in a physically small package to suit the intended environment. These devices have full operating systems and can support a large stack of software, including the capability to dynamically load software from a remote location. Storage capacity can be substantial and may include replicated and redundant storage to cope with hardware failures. Networking capabilities are likely to be substantial and can include both proximity networks and wireless or wired wide area networks.

The boundaries between these classes of edge entities are not hard and fast and are likely to change over time as technologies evolve. Systems that use edge computing are likely to have to deal with sets of edge entities that span all four classes, with impacts on the architecture and organization of the systems as a whole.

In addition, manageability is an important distinguishing characteristic of edge computing (i.e. servers in the field). While servers in the data centre are in tightly controlled environments with easy manual access, the ones in the field are not in controlled environments and manual access is difficult. So, they need to be hardened, monitored and managed remotely. They are also configured differently; for example, omitting ports (USB), to avoid tampering, etc.

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[1] Raspberry Pi is a trademark of Raspberry Pi Foundation. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC or ISO.

Due to the limited resources of edge computing entities (ECE), the coordination among ECEs is indispensable. ECE with different capabilities serve as distinct roles, such as smart devices with lightweight computing capability, smart gateways with capability of data collection, moderate computing, control, etc. and distributed computing system. The term "smart" in this document indicates things with intelligence and automation. For example, smart agriculture uses automated crop monitoring and management.

5.4 Example characteristics of edge computing

Through the use of edge computing, the following value can be added to solutions.

- Edge entities may provide data processing capability (including data analysis, processing, aggregation, privacy, security, etc.) with bounded latency, adaptation and agility.
- Provides support for data buffering for intermittent connections.
- Processing resources that are logically closer to the edge offer lower latency.
- Provides bounded latency that commits to a specific latency requirement.
- Guarantee geofencing of data for security, privacy, regulation or policy enforcement Provides support for connection under various network topologies. Dedicated use cases show different topology for connection of things. The topologies include mesh (in manufacturing, electricity, city, home, etc.), ring (in car, campus, etc.), star (in enterprise, campus, etc.), and others.
- Provides support for multiple network capabilities, including but not limited to network management, control, maintenance, VNF, smart routing, band steering.
- Edge entity manages data, determines lifecycle of data and creates value from data.
- Edge computing provides distributed security (such as authorization, authentication, white list, etc.)
- Edge computing supports coordination between edge and centralized data centres which may be providing cloud services. An ECE may be cooperating with multiple centralized data centres.

5.5 Stakeholders

The following is a list of typical stakeholder groups for edge computing, and some of the questions that those stakeholders might ask in relation to developing an edge system.

a) Developers

Persons who develop the applications and services for the edge computing system.

- How do we develop applications for the edge computing system?
- How do we update the software on the edge devices, IoT gateways and centralized data centres without interrupting the running applications?

b) Architects

Persons who design the architecture of the edge computing system.

- How do we design architectures to meet bounded latency requirements?
- How do we realize a scalable and resilient network that supports a dynamically increasing number of connections?
- How do we distribute workloads among resources to meet the requirements of the system?
- How do we achieve bridging and interoperability between distributed computing resources used for edge computing across different application domains?
- How do we orchestrate resources, including computing, storage, and networking, to satisfy the requirements of stakeholders?
- How do we integrate the cross-boundary technologies onto the edge computing system?
- How do we manage intermittent or unavailable connections between ECEs?

c) Service providers

Persons or organizations that undertake commercial or industrial activities using the edge computing system.

– How do we improve efficiency by using the edge computing services?

– How do we reduce the cost of service deployment?

– How do we increase the profit from running the applications and services in the edge computing system?

d) Equipment manufacturers

Persons or organizations that produce the devices used in the edge devices, IoT gateways, centralized data centres, or other edge computing-related devices.

– How do we design edge computing entities that can integrate easily into an edge computing system?

– How do we ensure that edge computing entities are manageable within an edge computing system?

– How do we ensure that edge computing entities have appropriate security and privacy capabilities?

e) Users

Persons who use the edge computing system.

– How do we interact with edge computing systems?

– How do we interact with physical edge computing entities?

– How do we interact with virtual edge computing entities?

f) Administrators

Persons who manage the edge computing systems.

– How do we manage/use the edge computing systems?

– How do we improve the efficiency to manage the IoT devices?

– How do we monitor the status of IoT devices?

– How do we achieve predictive maintenance?

– How do we process personally identifiable information (PII) in compliance with regulatory requirements or an organization’s policies?

g) Security personnel

Persons who manage edge computing related information security threats and risks.

– How do we meet privacy and security requirements in the edge computing system?

h) Consumers

People who purchase edge computing devices and related services for their own personal use.

– How do we protect data that is stored and transmitted through the edge computing devices?

– How do we secure the edge computing devices and receive timely security updates as necessary through the life of the product?

– Where consumer data is processed outside the control of the consumer, for example in a centralized service, is that processing made clear to the consumer and are clear statements made about the limitation of processing and removal of consumer data after a specified period of time?