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IPv6-based Internet of Things
Deployment of IPv6-based Internet of Things

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) IPv6 Integration (IP6).

Modal verbs terminology

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Executive summary

The present document summarizes the advantages and benefits of IPv6 in the deployment of IoT solutions.

It first analyses the IoT landscape, its evolution and its principal characteristics. It then focuses on the principal motivations for IPv6 in this environment both from a technical standpoint as well as from a standardization effort.

The next step is to underline the impact of the IoT toward the IPv6 specifications and its necessary evolutions.

The present document also describes an existing very large deployment of IPv6 in the Smart Grid area (multi-millions of devices).

1 Scope

The present document outlines the motivation for IPv6 in IoT, the technical challenges to address IoT on constrained devices and networks, the impact on the IPv6 technology and protocols, the technology guidelines, the step by step process, the benefits, the risks, as applicable to IoT domains including: M2M, Energy, Industrial, Mining, Oil and gas, Smart city, Transportation (including EVs), etc.

IPv6-based IoT in this context refers to the connectivity network layers needed to support the communication between things. It is understood that a complete IoT system may use of an IoT architecture including but not necessarily an abstraction layer part of an IoT platform. The description of such IoT platform is out of the scope of the present document.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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NOTE: Available at http://www.ieee802.org/15/pub/TG4.html.

[i.2] IEEE 1901.2a™-2015: "IEEE Standard for Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications - Amendment 1".

NOTE: Available at https://standards.ieee.org/findstds/standard/1901.2a-2015.html.

[i.3] IETF RFC 6296: "IPv6-to-IPv6 Network Prefix Translation".

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[i.4] IETF RFC 4291: "IP Version 6 Addressing Architecture".

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[i.5] IETF RFC 4193: "Unique Local IPv6 Unicast Addresses".

NOTE: Available at https://tools.ietf.org/html/rfc4193.

[i.6] IETF RFC 6690: "Constrained RESTful Environments (CoRE) Link Format".

NOTE: Available at https://tools.ietf.org/html/rfc6690.

[i.7] IETF RFC 7252: "The Constrained Application Protocol (CoAP)".

NOTE: Available at https://tools.ietf.org/html/rfc7252 [i.8] IETF RFC 7390: "Group Communication for the Constrained Application Protocol (CoAP)".

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[i.9] IETF RFC 7641: "Observing Resources in the Constrained Application Protocol (CoAP)".

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[i.10] IETF RFC 4861: "Neighbor Discovery for IP version 6 (IPv6)".

NOTE: Available at https://tools.ietf.org/html/rfc4861.

[i.11] IETF RFC 2460: "Internet Protocol, Version 6 (IPv6) Specification".

NOTE: Available at https://tools.ietf.org/html/rfc2460.

[i.12] IETF RFC 4944: "Transmission of IPv6 Packets over IEEE 802.15.4 Networks".

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[i.13] IETF RFC 6282: "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks".

NOTE: Available at https://tools.ietf.org/html/rfc6282.

[i.14] IETF RFC 6775: "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)".

NOTE: Available at https://tools.ietf.org/html/rfc6775.

[i.15] IETF RFC 7428: "Transmission of IPv6 Packets over ITU-T G.9959 Networks".

NOTE: Available at https://tools.ietf.org/html/rfc7428.

[i.16] IETF RFC 6437: "IPv6 Flow Label Specification".

NOTE: Available at https://tools.ietf.org/html/rfc6437.

[i.17] IETF RFC 5072: "IP Version 6 over PPP".

NOTE: Available at https://tools.ietf.org/html/rfc5072.

[i.18] IETF draft-ietf-roll-applicability-ami-15: "Applicability Statement for the Routing Protocol for Low Power and Lossy Networks (RPL) in AMI Networks".

NOTE: Available at https://tools.ietf.org/html/draft-ietf-roll-applicability-ami-15.

[i.19] IEEE 802.11™: "IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[i.20] IEEE 802.15.4g™: "IEEE Standard for Local and metropolitan area networks--Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 3: Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks".

[i.21] IETF RFC 3027: "Protocol Complications with the IP Network Address Translator".

[i.22] IEEE 802.15.4e™: "IEEE Standard for Local and metropolitan area networks--Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC sublayer".

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[i.25] Recommendation ITU-T G.9959: "Short range narrow-band digital radiocommunication transceivers - PHY, MAC, SAR and LLC layer specifications".

[i.26] IEEE 802.11ah™: "IEEE Standard for Information technology--Telecommunications and information exchange between systems - Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 2: Sub 1 GHz License Exempt Operation".

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[i.28] Recommendation ITU-T G.9905: "Centralized metric-based source routing".

[i.29] draft-ietf-6lo-nfc: "Transmission of IPv6 Packets over Near Field Communication".

[i.30] draft-ietf-6tisch-architecture: "An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4".

[i.31] IEEE 802.3™: "IEEE Standard for Ethernet.

[i.32] IETF RFC 6272: "Internet Protocols for the Smart Grid".

[i.33] IEEE 802.16™: "IEEE Standard for Air Interface for Broadband Wireless Access Systems".

[i.34] IEC 61968: "Application integration at electric utilities - System interfaces for distribution management".

[i.35] IEC 61850: "Communication networks and systems for power utility automation".

[i.36] IEC 60870: "Telecontrol equipment and systems".

[i.37] ANSI C12.22: "Protocol Specification For Interfacing to Data Communication Networks".

[i.38] IEEE 802.1X™: "IEEE Standard for Local and metropolitan area networks--Port-Based Network Access Control".

[i.39] IEEE 802.11i™: "IEEE Standard for information technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 6: Medium Access Control (MAC) Security Enhancements".

[i.40] IETF RFC 2464: "Transmission of IPv6 Packets over Ethernet Networks.

[i.41] draft-ietf-6lo-dect-ule: "Transmission of IPv6 Packets over DECT Ultra Low Energy".

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3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	Third Generation Partnership Project
AAA	Authentication, Authorization, and Accounting
AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
API	Application Programmable Interface
ARIN	American Registry for Internet Numbers
ATM	Asynchronous Transfer Mode
AVB	Audio Video Bridging
B2B	Business-To-Business
BACNET	Building Automation and Control Networks
BT-LE	Bluetooth - Low Energy
CapEx	Capital Expenditure
CoAP	Constrained Application Protocol
CoRE	Constrained Restful Environments

COSEM	Companion Specification for Energy Metering
CPU	Central Processing Unit
DA	Distributed Automation
DAD	Duplicate Address Detection
DCC	Data Communications Company
DECT	Digital Enhanced Cordless Telephone
DECT-ULE	DECT Ultra Low Energy
DHCP	Dynamic Host Configuration Protocol
DLC	Data Link Control
DLMS	Device Language Message Specification
DNS	Domain Name System
DPI	Deep Packet Inspection
DR	Demand Response
DSO	Distribution System Operator
DTLS	Datagram Transport Layer Security
E-IGRP	Extended - Interior Gateway Routing Protocol
ETSI	European Telecommunications Standards Institute
ETX	Extended Transmission metric
EV	Electric Vehicle
FA	Factory Automation
FAN	Field Area Network
FAR	Federal Acquisition Regulation
FAR	Field Area Router
FR	Frame Relay
GPRS	General Packet Radio Service
GSM	Global System for Mobile (communications)
HAN	Home Area Network
HTTP	HyperText Transfer Protocol
IANA	Internet Assigned Number Association
ICMP	Internet Control Message Protocol
ICT	Information and Communication Technology
IDS	Intrusion Detection Service
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronic Engineers
IESG	Internet Engineering Steering Group
IETF	Internet Engineering Task Force
IoT	Internet of Thing
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IPX	Internetwork Packet eXchange
IS-IS	Intermediate System to Intermediate System
ISP	Internet Service Provider
IT	Information Technology
ITU	International Telecommunication Union
LLN	Low Power and Lossy Network
LORA	LOng RAnge
LPWA	Low Power Wide Area
LPWAN	Low Power and Wide Area Networking
LTE	Long Term Evolution
LTE-MTC	LTE-Machine Type Communication
LTN	Low Throughput Network
M2M	Machine to Machine
MAC	Media Access Control
MDMS	Meter Data Management System
MP2P	Multi-Point-to-Point
MP-BGP	Multi Protocol-Border Gateway Protocol
MS/TP	Master-Slave/Token-Passing
MTC	Machine Type Communication
MTU	Maximum Transmission Unit
NAN	Neighbour Area Network
NB-IoT	Narrow Band-IoT

NB-PLC	Narrow Band-Power Line Communications
NFC	Near Field Communication
NMS	Network Management System
NOC	Network Operation Centre
NPT	Network Prefix Translation
OMB	Office of Management and Budget
OPEX	OPerational EXpenditure
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
OT	Operational Technology
P2P	Point-to-Point
PC	Personal Computer
PD	Prefix Delegation
PDR	Packet Delivery Ratio
PHY	PHYsical layer
PIM	Protocol Independent Multicast
PLC	Power Line Communications
PNNI	Private Network to Network Interface
QoS	Quality of Service
RAM	Random Access Memory
RF	Radio Frequency
RFC	Request For Comments
RIP	Routing Information Protocol
RIR	Regional Internet Registry
RoLL	Routing over LLN
RPL	Routing Protocol for LLN
RS	Recommended Standards
SAE	Society of Automotive Engineers
SEP	Standard Energy Profile
SMB	Standard Management Board
SNA	Systems Network Architecture
SNMP	Simple Network Management Protocol
SSH	Secure SHell
TC	Technical Committee
TCP	Transport Control Protocol
TSCH	Time Slotted Channel Hopping
TSN	Time Sensitive Networking
UDP	User Datagram Protocol
UNB	Ultra Narrow Band
VPN	Virtual Private Network
WAN	Wide Area Network
WG	Working Group
WIA	Wireless Industrial Automation
WI-SUN	Wireless-Smart Ubiquitous Network
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

4 User defined clause(s) from here onwards

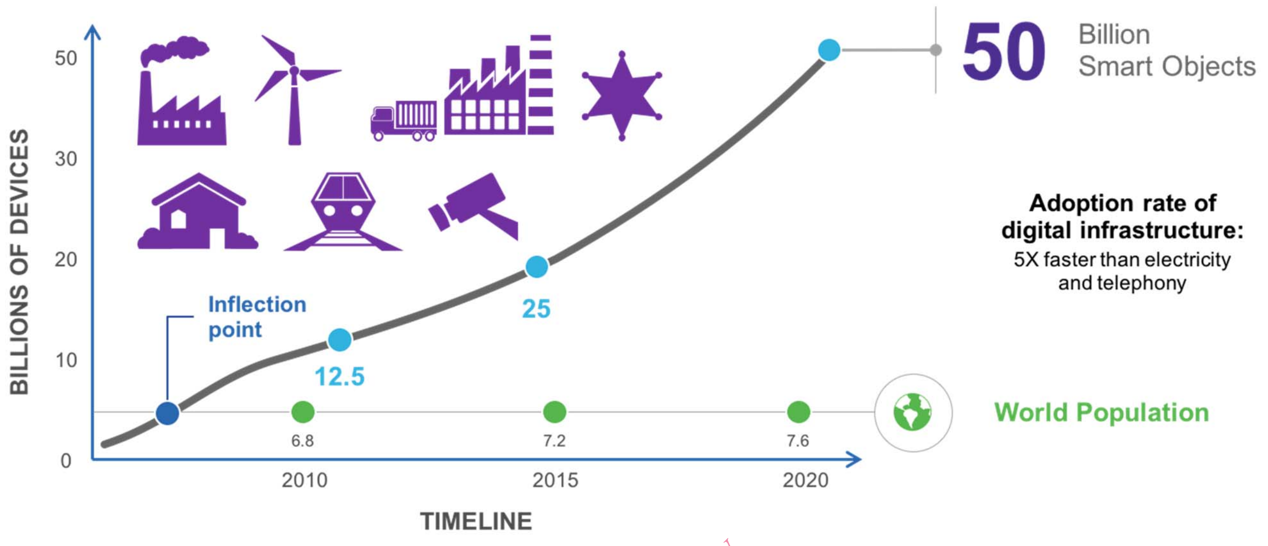
4.1 Introduction

4.1.1 The IoT in 2020: 50 Billion of connected devices

The number of Internet Connected devices will cross the incredible total of 50 billion by 2020.

The connectivity fabric of IP is used to enable more and more efficient context exchange with a broader range of devices and things. Thus, results the Internet of Things.

Projected to increase device counts by orders of magnitude over the next few decades, IoT's impact cannot be overstated. Already enabling a rich set of new capabilities in Smart Cities, Smart Grid, Smart Buildings, and Smart Manufacturing, IoT stands to transform virtually every part of modern life that automation or visibility may improve.



Source Cisco

Figure 1: IoT growth

4.1.2 IoT connectivity: Wired and Wireless

No matter the precise forecast, the sheer tsunami of devices coming online in the next months, years, and decades ensures that the future is not exclusively, or even significantly, wired.

Wireless with its adaptability and ease will inevitably dominate the IoT landscape. Exactly which wireless technology or technologies will be used remains relatively unclear, as many new technologies are still emerging, while others are still early in the standards process.

The challenges IPv6 poses to high bandwidth wireless networks are well-known. However, low bandwidth links, like LPWAN (Low Power Wide Area Network), do require optimization and broadly adapt and adopt techniques like IPv6 header compression.

Clause 4.4 is describing the IETF technologies to adapt IPv6 to different constraint media. This problem is not specific to the use of IPv6 but due primarily to the scale of IoT deployment.

The following list summarizes the main different wireless technologies used for IOT:

- IEEE 802.15.4 [i.1] WPAN: The IEEE 802.15 TG4 was chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. It is operating in an unlicensed, international frequency band. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation.
- IEEE 802.11 [i.19] WLAN (Wireless Local Area Network).
- LPWAN (Low Power and Wide Area Network).
- Cellular Networks (NB-IoT, 5G).

New PLC (Power Line Communications) technologies are also emerging like IEEE 1901.2a [i.2]. These technologies offer the capability to use the same wire for power supply and communication media.

4.1.3 Constraint devices and constraint networks

4.1.3.1 The Unique Requirements of Constrained Networks

Devices deployed in the context of Neighbour Area Networks (NANs) are often constrained in terms of resources and often named IP smart objects. Smart-object networks are also referred to as low-power and lossy networks (LLNs) considering their unique characteristics and requirements.

As a contrast with typical IP networks, in which powerful routers are interconnected by highly stable and fast links, LLNs are usually interconnected by low-power, low-bandwidth links (wireless and wired) operating between a few kbps and a few hundred kbps and forming a meshed network for helping to ensure proper operations. In addition to providing limited bandwidth, it is not unusual to see on such links the packet delivery ratio (PDR) oscillating between 60 % and 90 %, with large bursts of unpredictable errors and even loss of connectivity at intervals. Those behaviours can be observed on both wireless (such as IEEE 802.15.4g [i.20]) and Power Line Communications (PLC) (such as IEEE 1901.2a [i.2]) links, where packet delivery variation may happen during the course of one day.

4.1.3.2 Energy consumption in the IoT

Some estimates of IoT have placed the number as high as 50 %, the devices that will be constrained by battery power and also require long-range, wide-area connectivity. Managing these volumes of batteries is no small task, especially given requirements from end-users in utilities and manufacturing asking for 10 to 20 years of battery life.

The sheer size of IoT market and associated communications infrastructure intensifies the importance of energy efficiency awareness. Without significant thought and effort, it is easy to reach very high levels of aggregate power consumption with these technologies. Normalizing the interface fabrics to IPv6 architectures and eliminating needless protocol translation functions is an enormous step towards overall efficiency and prudence.

4.2 The IoT landscape

4.2.1 The Convergence of IT and OT

Converging Networks for the Industrial Internet

Operational Technology (OT) often refers to industrial networks, which focus on highly reliable, secure and deterministic networking. In OT environments, deterministic networks are characterized as providing a guaranteed bandwidth with extremely low packet loss rates, bounded latency, and low jitter. OT networks are typically used for monitoring systems and supporting control loops, as well as movement detection systems for use in process control (i.e. continuous manufacturing) and factory automation (i.e. discrete manufacturing), and protection systems in the SmartGrid.

Due to its different goals, OT has evolved in parallel but in a manner that is radically different from Information Technology/Information and Communications Technology (IT/ICT), which relies on selective queuing and discarding of IP packets to achieve end-to-end flow control over the Internet.

The motivation behind the so-called Industrial Internet is that a single percentile point of operational optimization may save billions of dollars across multiple industries. This optimization requires collecting and processing of huge amounts of missing measurements utilizing widely distributed OT sensing and IT analytics capabilities.

In order to avoid skyrocketing operational costs, the Industrial Internet should share the same infrastructure (network and management) as the deterministic OT flows. This means that the Industrial Internet vision can only be achieved through the convergence of IT and OT, whereby the network becomes capable of emulating the properties of deterministic OT circuits in the same fabric that serves traditional best effort IP applications.

This convergence is made possible by for example the newly introduced open standards for Deterministic Networks that are developed to enable traffic that is highly sensitive to jitter, requires bounded latency in the worst case scenario, and has a high degree of operational criticality so that packet loss should be reduced dramatically, over a converged switched packet fabric.