**IEEE P802.15**

**Wireless Personal Area Networks**

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| Project | IEEE P802.15 Working Group for Wireless Specialty Networks (WSN)s | |
| Title | **Contribution to the ITU SG20 on behalf of IEEE 802.15** | |
| Date Submitted | 8 November, 2016 | |
| Source | [] [] [address] | Voice: [ ] Fax: [ ] E-mail: [ ] |
| Re: | In response to Sébastien Ziegler’s request :  ITU-T Study Group 20 would like to invite the IEEE, and in particular its bodies specialized in the IoT, such as the ComSoc Internet of Things Emerging Technologies Subcommittee, to share and submit any relevant information and document on the above mentioned work items, including more specifically:   * Examples, models and use cases of IPv6 subnet addressing plans encompassing the Internet of Things; * Any suggestion on IPv6 subnet addressing plan design; * Information and documents on IPv6-compliant communication protocols and standards for the Internet of Things; | |
| Abstract | [IEEE 802.15 Overview along with specifics on 802.15.4 and 802.15.12] | |
| Purpose | [Request that 802.15 WG approve this contribution to ITU SG20] | |
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| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. | |

## Introduction

The purpose of this document is to share information with ITU-T Study Group 20 on the IEEE 802.15 work group projects, particularly those that associated with IPv6 and the Internet of Things (IoT). Accordingly, in addition to the brief descriptions on each IEEE 802.15 project, this paper describes additional detail on IEEE 802.15.4 and a companion project IEEE 802.15.12.

The focus of this paper was influenced by the document “The Internet of Everything through IPv6: An Analysis of Challenges, Solutions and Opportunities.[[1]](#footnote-1)”

## IEEE 802.15 Overview

For almost two decades, the IEEE 802.15 Working Group has been involved in the forefront of the internet of things (IoT) with standards focused upon machine to machine (M2M) applications with little if any human interaction. The increasing recognition of the benefits from IoT have dramatically increased the usage of 802.15 standards.

IEEE 802.15 includes a family of complementary standards dealing with diverse applications in the consumer, industrial, and commercial spaces. Industry wide uptake and ongoing developments continue for several of the 802.15 works streams (primary Task Groups) including 802.15.3, 802.15.4, 802.15.6, 802.15.7, 802.15.8, 802.15.9, 802.15.10, and 802.15.12:

* 802.15.3 provides high data rate over short distances for the efficient transfer of large data payloads with very little overhead. Two ongoing projects in this family are:
  + 802.15.3d - wireless switched point-to-point physical layer operating at peak data rates of almost 250 Gb/s with fallbacks to lower data rates as needed. Frequency band ranges from 252 GHz to 325 GHz at distances as short as a few centimeters and up to several hundred meters; and
  + 802.15.3e - defines a Physical (PHY) layer using unlicensed 60 GHz spectrum with additions to the Medium Access Control (MAC) sublayer which enable close proximity (typically 10 cm or less), high rate (up to almost 150 Gbps) communications with at least one mode of operation that is capable of achieving connection set up times of 2 ms or less.
* 802.15.4 (see detail) defines a low data rate, low cost, and low energy wireless standard with simple implementation for small payloads and periodic communication needs over a long period of time unattended.
* 802.15.6 defines Body Area Networks, featuring low energy and high reliability for implant devices, and other medical sensing, all of which enable remote monitoring of patients by doctors helping to curb against increasing health care costs.
* 802.15.7 - defines optical link networks using devices such as the flash, display and image sensor as the transmitting and receiving devices for point of service areas, driver information using street lights, and commercial communication using light fixtures. The most recent project is focused on short-range optical wireless communication. A typical application would be optical communications for cameras where transmitting devices incorporate light emitting sources and receivers are digital cameras with a lens and image sensor.
* 802.15.8 standardizes Peer Aware Communications (PAC) for peer to peer and infrastructure-less communications with fully distributed coordination.
* 802.15.9 Key Management Protocol (KMP) Recommended Practice - describes support for transporting KMP datagrams to support the security functionality present in 802.15.4, including the definition of a general purpose multiplexed (MPX) data service supporting fragmentation, re-assembly, and protocol dispatch for payloads unable to fit in a single MAC frame.
* 802.15.10 Layer 2 Routing (L2R) Recommended Practice - defines a protocol that routes packets in a dynamically changing 802.15.4 network with minimal impact from route management. The result is an extension of the area of coverage as the number of nodes increases.
* 802.15.12 Upper Layer Interface for 802.15.4 (see detail) - defines an L2 sublayer above the 802.15.4 MAC that provides standardized configuration and enables services to multiple higher layer protocols.

## IEEE Std 802.15.4 detail

Of the 802.15 standards, 802.15.4 is by far the most popular and prolific due to its focus on remote sensors and monitoring, with 100’s of millions of devices deployed. To accommodate the anticipated large quantities of these types of devices, 802.15.4 was first 802 standard to use the IEEE 64-bit MAC address, using an IEEE organizationally unique identifier (OUI), making it appropriate for IPv6 networks. The 802.15.4 project was started in November 2000 and it was approved in May 2003. Since then there have been 3 revisions and 13 approved amendments.

The 802.15.4 standard is focused on low cost and low complexity devices, with low energy consumption for long battery life or use of an energy harvesting power source. This standard was designed from the beginning to work within mesh networks to extend the network coverage and link reliability while still maintaining low power and low energy consumption.

This standard consists of a MAC sublayer and a variety of physical layers. The MAC is very configurable and flexible, allowing applications to elide unnecessary fields and disable optional behaviors as appropriate. To address diverse applications, the physical layers cover frequencies ranging from 169 to 10,600 MHz, along with data rates ranging from 2.4 kb/s to 27.24 Mb/s. Finally, 802.15.4 is also very diverse in that it supports communication distances from a few feet up to several kilometers. Additional detail may be found in Appendix A.

As a result of its capabilities and flexibility, the 802.15.4 standard has received widespread acceptance from Consortiums and Alliances such as ZigBee, Thread, HART, and Wi-SUN, as well as standards development organizations such as ISA (ISA100.11a/62734), TIA (TR-51), IETF (6lo & 6tisch), ISO/IEC (24730-62), and ETSI (TS 102 887-1)[[2]](#footnote-2).

Applications and uses for 802.15.4 devices and networks include:

* Smart Utility Network (SUN): Utility applications for both the HAN and FAN spaces, including AMI and Smart Grid for Electric Meters, Gas Meters, and Water Meters
* Industrial wireless networks for industrial automation and process control
* Lighting control networks for commercial buildings that are easily configured, energy efficient, and user friendly
* Home Automation applications such as remote controls, lighting and HVAC controls
* Medical applications including patient care connecting sensors to medical devices, and remote patient monitoring (reducing hospital stays)
* Critical Infrastructure (low power, wide area networks): long range, point-to-multipoint architecture for monitoring pipelines, electrical vaults, and perimeters
* Active RFID applications, including precision location awareness, such as asset management, inventory management, process control and automation, safety and accountability
* Railway: in applications such as positive train control
* International Space Station for asset tracking and control
* Consumer electronics such as cable/set-top boxes, integrated A/V, and home theatre control

Currently, there are four ongoing amendments to 802.15.4:

802.15.4s Defines MAC related functions to enable spectrum resource management

802.15.4t Increases the data rate of the 2.4 GHz O-QPSK PHY from 0.25 to 2 Mb/s

802.15.4u Adds the 865 – 867 MHz band in India

802.15.4v Adds following bands: 870-876 MHz and 915-921 MHz spectrum in Europe, 902-928 MHz band in Mexico, 902-907.5 MHz & 915-928 MHz band in Brazil, 915-928 MHz band in Australia/ New Zealand; additionally, the 470-510 MHz band in China and the 863-870 MHz band in Europe and their channel parameters need to be aligned with the updated regional requirements

It is also notable that the 802.15.9 and 802.15.10 recommended practices are focused on 802.15.4 as is the 802.15.12 project as described below.

## IEEE P802.15.12 detail

Although the 802.15.4 standard has been successful and is extremely popular with vendors and users, it has some drawbacks for certain classes of applications:

* Each user application requires a unique protocol stack to interface to the 802.15.4 MAC and configure the 802.15.4 MAC and PHY
* 802.15.4 couldn’t serve multiple higher layer protocols as there is no protocol discrimination mechanism in the MAC such as EtherTypes
* Older versions of 802.15.4 didn’t address many of the new application needs, hence user application stacks added their own enhancements
* Security on older versions of 802.15.4 did not function correctly, requiring user application stacks to either use their own security or work around the security flaws

Due to the above issues along with the complexity of 802.15.4 protocols and misunderstanding of how to use specific 802.15.4 modes and the performance gains they can give, some applications have chosen to either not use the 802.15.4 standard or to only use aspects of 802.15.4.

Accordingly, the 802.15.12 project was started in May 2016 with the following goals:

* Make 802.15.4 easier for applications to use, similar to IEEE 802.11 (WiFi) and IEEE 802.3 (Ethernet)
* Enable 802.15.4 to use multiple higher layer protocol stacks such as those used by 802.11 and 802.3
* Allow 802.15.4 to address new applications yet maintain backward compatibility with existing devices and applications

When completed the 802.15.12 standard will:

* Define a method to configure the 802.15.4 MAC and PHY with security, network, and channel settings via defaults or settings received via an out-of-band means
* Enable IC or stack vendors to provide consistent and standardized mechanisms to set up networks and links
* Enable 802.15.4 to address new applications in areas such as IoT or to better address existing applications
* Allow 802.15.4 to fully integrate with IPv6 and other IETF protocols by integrating existing upper L2 protocols such as 6lowpan, KMP, L2R, and 6tisch.

## 6LoWPAN

As noted earlier, IEEE 802.15.4 has been tremendously successful in addressing the needs for wireless machine to machine (M2M) communications; but in doing so reduced the frame length and data rates from typical web-based IPv6 traffic. To address these limitations 6LoWPAN was created to define fragmentation and header compression methods when using IPv6 over 802.15.4.

The dominant version of 802.15.4 to date uses a maximum frame length of 127 octets[[3]](#footnote-3), as opposed to the minimum supported IPv6 length of 1280 octets, hence the need for fragmentation. Header compression is also needed since the shortest header of TCP/IPv6 datagrams is 60 octets and the shortest header of UDP/IPv6 datagrams are 48 octets which when added to a typical MAC overhead of 15 octets[[4]](#footnote-4) yields either a maximum payload ranging from 39 to 64 octets or a minimum frame size of 63 to 88 octets.

RFC 6282 updates RFC 4944 by defining an encoding format, LOWPAN\_IPHC, for better compression of Unique Local, Global, and multicast IPv6 addresses based on shared state within contexts.

While RFC 4944 and RFC 6282 effectively compress the IPv6 and TCP/UDP headers, any changes that would allow greater compressions would greatly help constrained devices, especially low power wide area network (lp-wan) devices.

## 6tisch

6tisch combines a high speed powered backbone and subnetworks using 802.15.4 time-slotted channel hopping (TSCH) to meet the requirements of low power wireless deterministic applications. Management of the 6tisch system is distributed. Industrial Automation networks for process control such as IEC 62734 provide a similar functionality but use a single centralized network manager.

The assignment of time slots on a given channel allow end devices and routing devices to minimize their “on” time, saving energy, reducing RF interference, and increasing spectral efficiency.

## 802.15.4 EcoSystem and the IoT

As previously described, there are many standards and specifications, both complete and in the process of development, that work with 802.15.4 to address attributes such as large coverage areas, long ranges, large number of devices, minimal device energy consumption, and minimal device complexity.

Additionally, there are higher layer protocols from the IETF such as CoMI, CoAP, 6lo, Ace, CoRAL, and core focusing on enabling constrained devices such as 802.15.4 to participate in systems with functions such as building automation, utility meter reading, industrial automation, healthcare, and home automation.

To allow the 802.15.4 device to use multiple higher layer protocols, 802.15.12 adds protocol discrimination which will direct the incoming/outgoing datagram to the correct higher layer protocol. For example, an 802.15.4 device could participate in a SUN network but also participate in a building automation application or in an IoT application.

## Conclusion

The IEEE Std 802.15.4 along with companion standards and specifications, such as IEEE 802.15.12 that integrates 6LoWPAN, 6tisch, KMP, and L2R, will allow new IoT applications to be wirelessly connected for very long periods of time in a very cost effective and reliable manner.

## Appendix A

This appendix describes additional details on the 802.15.4 MAC and PHY.

To address the various applications throughout the world, the 802.15.4 PHY includes the following modulations: FSK (frequency shift keying), BPSK (binary phase shift keying), O-QPSK (offset quadrature phase shift keying), OFDM (orthogonal frequency division multiplex), MSK (minimum shift keying), ASK (amplitude shift keying), CSS (chirp spread spectrum), and UWB (ultra wide band).

The MAC sublayer has numerous modes and optional behaviors. The modes include: guaranteed time slot (GTS), deterministic and synchronous multi-channel extension (DSME), time scheduled channel hopping (TSCH), low energy critical infrastructure (LECIM) also known as low power wide area network (LP-WAN), radio frequency identification (RFID), and railroad control communications (RCC) also known as positive train control.

Additionally, the MAC sublayer has many optional behaviors including association, security, promiscuous behavior, SUN, television white space (TVWS), ranging, low energy, priority, metrics, channel hopping, information elements (IEs), and time-slot relaying based link extension (TRLE).

1. The “The Internet of Everything through IPv6: An Analysis of Challenges, Solutions and Opportunities” may be found at <http://ipv6forum.com/iot/images/jowua-v4n3-6.pdf> [↑](#footnote-ref-1)
2. In its liaison letter to 802.15, the ETSI TC ERM stated that “*802.15.4 standards are also important components of the M2M infrastructure leading to the Internet of Things.”* [↑](#footnote-ref-2)
3. The other frame size used by numerous 802.15.4 versions is 2047 octets [↑](#footnote-ref-3)
4. While the 802.15.4-2015 standard does not include a constant for previous “aMaxFrameOverhead”, the maximum MAC overhead would be significantly over 50 – 60 octets depending upon the IEs in the frame. [↑](#footnote-ref-4)