Thread 1.2 for Smart Buildings White Paper

September 2022

This Thread Technical white paper is provided for reference purposes only. The full technical specification is available publicly. To join gain access, please follow this link: https://www.threadgroup.org/ThreadSpec.

If there are questions or comments on these technical papers, please send them to help@threadgroup.org.

This document and the information contained herein is provided on an "AS IS" basis and THE THREAD GROUP DISCLAIMS ALL WARRANTIES EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO (A) ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY RIGHTS OF THIRD PARTIES (INCLUDING WITHOUT LIMITATION ANY INTELLECTUAL PROPERTY RIGHTS INCLUDING PATENT, COPYRIGHT OR TRADEMARK RIGHTS) OR (B) ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, TITLE OR NONINFRINGEMENT.

IN NO EVENT WILL THE THREAD GROUP BE LIABLE FOR ANY LOSS OF PROFITS, LOSS OF BUSINESS, LOSS OF USE OF DATA, INTERRUPTION OF BUSINESS, OR FOR ANY OTHER DIRECT, INDIRECT, SPECIAL OR EXEMPLARY, INCIDENTAL, PUNITIVE OR CONSEQUENTIAL DAMAGES OF ANY KIND, IN CONTRACT OR IN TORT, IN CONNECTION WITH THIS DOCUMENT OR THE INFORMATION CONTAINED HEREIN, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH LOSS OR DAMAGE.

Copyright © 2022 Thread Group, Inc. All rights reserved.

Thread 1.2 for Smart Buildings White Paper

September 2022

Revision History		
Revision	**Date**	**Comments**
1.0	September 2019	First Public Release
2.0	September 2022	Fully Revised Version

Table of Contents:

1. Authors: Jorg Kennis, Klaus Waechter, Sujata Neidig

2. Overview of Thread

Thread is an open standard for wireless communication providing a native IP (Internet Protocol) solution for reliable, low-power, secure, device-to-device, application agnostic communication. It is the premier IPv6 based solution running on existing and broadly supported IEEE 802.15.4 radio technology.

Thread offers a number of benefits compared to other solutions. Its IPv6 base enables flexible set-up, monitoring, data analysis, provisioning and a direct connection without compromising encryption and security, from local networks all the way up to the cloud. Thread also offers flexibility in choosing which application protocols to run, even allowing multiple application standards to run concurrently, enabling flexible integration with other technologies and maintaining an open path towards future developments.

Since Thread is based on IPv6, the application layers can also run on existing IP infrastructure like Wi-Fi and ethernet, allowing the most suitable networking technologies to be used together. For example, a network could consist of lighting end points connected with Thread and lighting end points connected via PoE, all operating in one fully integrated environment.

Today, the majority of building networks consist of technology silos, which also require separate security and maintenance efforts. Thread connectivity serves to provide a common IP (Internet Protocol) networking solution for easy integration with enterprise networks. This enables more flexibility in functionality planning, better system features, easier maintenance and lower cost. Thread scales to thousands of wireless robustly connected IP devices and handles both local communication between devices as well as cloud connectivity over the internet. In terms of self-configuring and re-configuring it brings a familiar way of setting up and managing the network for system administrators, without the need to worry about address and topology assignment. End-to-end routing and addressability allow IPv6 packets to securely move from one end point to the other, whether on the same Thread mesh network, or across the world. Its 6LoWPAN foundation is based on low-power, widely deployed, proven and low-cost IEEE 802.15.4 radio technology that supports sleepy nodes and reduces network overhead.

Thread is a seamless part of the enterprise network and allows the usage of various application-level protocols to integrate with existing infrastructure while maintaining the security and flexibility to commission and maintain end-devices. It also allows for the creation of various individual and group profiles and domains, even spanning multiple individual Thread mesh-networks.

Thread's proven, secure and widely deployed specification is currently in use for residential and smart building IoT applications. With its powerful enhanced features for specific commercial use cases, Thread 1.2 scales to reliably connect thousands of wireless products in commercial grade buildings.

On top of Thread 1.1's robust foundation, Thread 1.2 offers numerous benefits specifically aimed at large scale enterprise implementations, including:

- Enterprise-level security requirements
- Scalable Deployments
    - Scaling deployments by combining multiple Thread networks into one IP subnet
    - Segmenting deployments into multiple Thread networks
- Automatic roaming to nearby Thread networks
- Ability to assign a secure identity to every device in the network
- Direct access to advanced analytics
- Easy handover from installers to network commissioners
- Full device life-cycle management in an enterprise environment

The features of Thread 1.2 are designed to improve the scalability of Thread networks, by making them more responsive, and capable of a higher network density. New low power features further reduce the power consumption, channel utilization and communication latency of Battery Operated Devices. This enables even more efficient battery powered end products. New features for communication between multiple thread networks on the same LAN, and non-Thread devices on that LAN have been added. These features improve integration with traditional networks and allow a new level of scalability for the smart building market by connecting multiple Thread Networks.

3. The Need for a Secure, Mesh, IPv6 Networking Solution

Historically, the network of constrained embedded devices that we now call the "Internet of Things" typically used specialized, and often proprietary, communication protocols. By contrast, the internet and the World Wide Web are built on a layered stack of open standards, with each layer independent and not tied to a specific application. This is why the internet and its applications are so flexible and pervasive.

In recent years, technology has emerged that enables manufacturers to use internet standards with these constrained embedded devices, allowing devices and applications to be developed independently and run anywhere: in the cloud, on mobile devices, on in-home devices, and on in-business devices. At the same time, developments in low-power network technology and compression and packet-handling standards, such as the IEEE 802.15.4 standard and 6LoWPAN, enabled great leaps forward in low power consumption and network efficiency.

Since we're building for the Internet of Things, the Thread Group incorporated the internet and its open standards to create an Internet Protocol (IP) version 6 (IPv6)-based mesh networking protocol with 6LoWPAN as its foundation, running on standard IEEE 802.15.4 radios.

3.1. The Need for IPv6

IPv6 is the internet's next-generation network protocol, designed to supplement and eventually replace the earlier version of the Internet Protocol, IP version 4. IPv6 provides a number of critical advantages:

- Extreme address scalability: In order to communicate over the internet, computers and other devices must have unique sender and receiver addresses. These numeric addresses are known as Internet Protocol (IP) addresses. IPv6 allows for literally trillions of IP addresses, providing virtually unlimited address scalability.
- End-to-end routing and addressability: Two IPv6 endpoints, whether on the same Thread mesh, across networks, or across the world, can

communicate end-to-end with straightforward and well-understood internet routing, moving the packets from one endpoint to the other.
- Easy manageability: Unlike IPv4 networks, IPv6 networks are inherently auto-configuring, removing the need for users and system administrators to worry about address assignment, DHCP servers, etc.
- Well-known and familiar: IP networks are well known by engineers, developers, technicians, and system administrators, leveraging a rich base of tools, knowledge and experience.
- Flexible: IPv6 supports a rich variety of upper-layer protocols, including transports, sessions, security, and applications, and IPv6 is supported over a wide range of wired (e.g., Ethernet) and wireless (e.g., Thread, Wi-Fi) networking protocols.
- Compatible: IPv6 and IPv4 can coexist using well understood and widely deployed techniques. IPv6 networks such as Thread can be deployed within IPv4 infrastructures.

3.2. The Need for Low Power

The Thread specification is designed from the ground up to enable extremely low power consumption and efficient device communication, without sacrificing a positive end-user experience. Two technologies in particular, the IEEE 802.15.4 standard and 6LoWPAN, form the backbone of Thread's low-power solution.

As a point of comparison, in Ethernet links, a packet with the size of the IPv6 MTU (1280 bytes) is typically sent as one frame over the link. In the case of 802.15.4, 6LoWPAN acts as an adaptation layer between the IPv6 networking layer and the 802.15.4 link layer. It solves the issue of transmitting an IPv6 MTU by fragmenting the IPv6 packet at the sender and reassembling it at the receiver. 6LoWPAN also provides a compression mechanism that reduces the IPv6 header sizes sent over the air and thus reduces transmission overhead. The fewer bits sent over the air, the less energy is consumed by the device. Thread makes full use of these mechanisms to efficiently transmit packets over the 802.15.4 network.

Another important feature of 6LoWPAN is the ability to provide link-layer packet forwarding. It provides a very efficient and low overhead mechanism for forwarding multi-hop packets in a mesh network. Thread uses IP layer routing with link-layer packet forwarding. It makes use of the 6LoWPAN link-layer forwarding capabilities to forward a packet, which avoids having to send it up to the network layer during packet transit. Thread uses the MAC layer to provide addressing based on short addresses (16-bit length) to further reduce the information sent over the air. This saves processing cycles and improves power efficiency, while still using an IP-based routing protocol.

Thread's low-power advantages:

- Extensive support for sleepy nodes which allows for years of device operation, even on a single AA battery
- Based on the power efficient IEEE 802.15.4 MAC/PHY
- Short message size conserves bandwidth and power
- Streamlined routing protocol reduces network overhead and latency
- Designed to run on readily available, low-power wireless system-on-chips

3.3. Security at Every Layer of the Stack

Thread provides end-to-end security because of its IP based foundation. There is no need for translation or decryption and re-encryption of data packets. A Thread Border Router simply transfers the data packets to and from the Thread network to the rest of the IP network infrastructure.

The Thread Network is protected with a network-wide key, which is used at the MAC (Media Access Control) layer to protect the IEEE 802.15.4 MAC data frames. This is an elementary form of security used to prevent casual eavesdropping and targeted disruption of the Thread Network from outsiders without knowledge of the network-wide key. As it is a network-wide key, compromise of any Thread Device could potentially reveal the key; therefore, it is not typically used as the only form of protection within the Thread Network. In addition, Thread uses the DTLS protocol for internet-grade end-to-end security when commissioning, and may use CASE, PASE, TLS or other encryption methods, based on the used application layer.

From the point of view of joining new devices into a network, the possession of the network key is used to discriminate between an authenticated and authorized Thread Device and the joining device (in its initial state). The network-wide key, along with other network parameters, is delivered securely to a joining device. This way, the network key is never exposed in the clear on a wireless link.

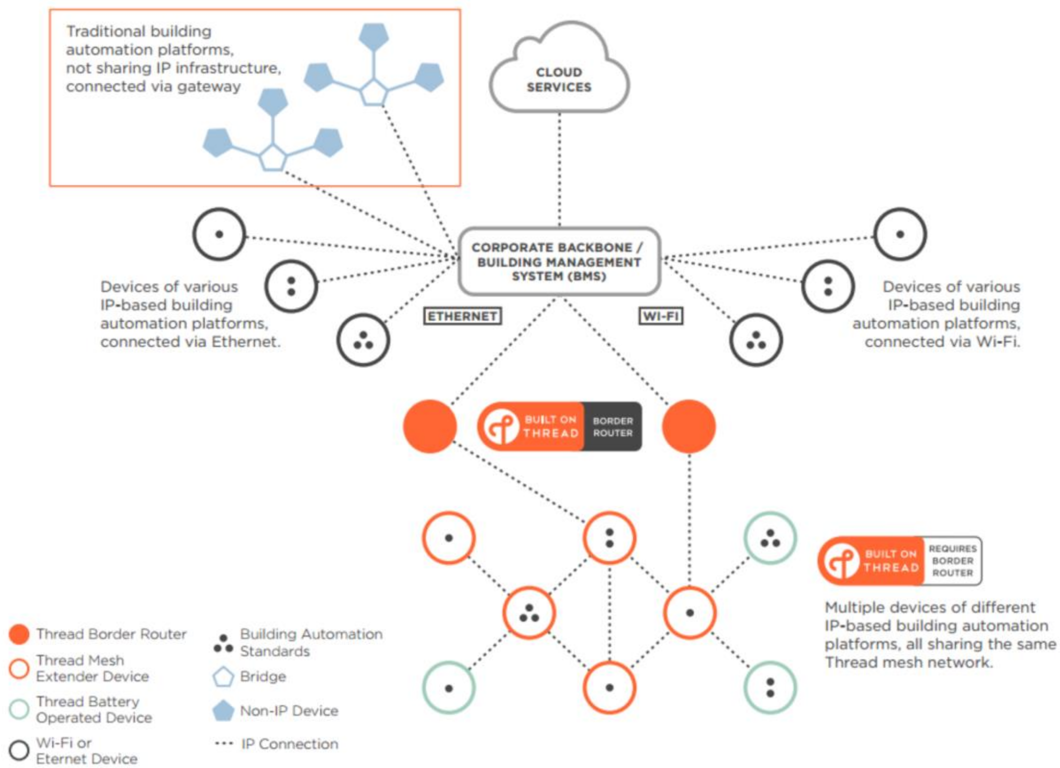
3.4. Benefits for Building Automation and Lighting Control Installations

In addition to the general benefits of IPv6 and low power consumption, Thread's wireless mesh IPv6 solution offers further specific advantages to a variety of applications:

- Professional building owners will be able to install both small networks (such as a quick-fix retrofit RF solution) and very large building networks (thousands of nodes) using the same networking technology, simplifying and streamlining network installation and management processes and overhead.
- Wireless IPv6 technology is forward-compatible, more sustainable, and offers greater economies of scale than alternative technologies, so networking solutions become more cost-efficient and add functionality more easily.
- Network managers, application managers, and system integrators can independently execute tasks on the system, easing network management bottlenecks.
- A native IP system can collect and process vast amounts of data, from a broad range of intelligent connected devices, in near real-time. System data can then be accessed directly or via the cloud. Unique value can be extracted through advanced analytics.
- The flexibility of the application stack enables more sophisticated occupant individual control possibilities, increasing the levels of convenience, productivity, and operational efficiency.
- The network is easier to reconfigure than alternative technologies, implying decreased refurbishment costs and lower churn cost in buildings.
- The technology further enables remote- and predictive maintenance, provides more opportunity for notifications on maintenance tasks, and simplifies system-wide fixes, software updates and network-reconfigurations.

- During building refurbishing, wireless technology requires less physical alteration of the site, reducing installation costs and offering increased flexibility and installation speed.

4. Topology of Thread in a Smart Building Network



The above topology diagram shows an example of how Thread can be implemented in an enterprise network environment. The diagram illustrates Thread's key advantage over other networking technologies: it is fully based on IPv6. Thread’s IPv6 based foundation brings many advantages to the Smart Building. Not only can it leverage widely proven cyber security mechanisms, but it can also integrate seamlessly in the existing building network infrastructure. Contrary to legacy automation systems, which are usually siloed in separate networks for each application, multiple applications

-even those based on different standards and protocols- can share the same network at the same time, and use the most appropriate physical network type for each individual device. Thread's low power mesh network is ideal for power constrained device types covering wide areas in a building.

In this article, we will explain the various parts of a Thread network, describe their purposes, and explain how they operate in the context of a wider building network. It shows how easy it is to integrate with existing products and how it allows for the maintenance and expansion of the network by network managers, independent from application and system integrators.

4.1. Thread Mesh Extender Device

Thread is a mesh network technology, which means a device on the network can not only receive data, but also pass data along to other devices. In this way, these devices act as Thread Mesh Extender devices. This results in a very stable network with a large reach, without the need for additional repeaters that rebroadcast wireless signals to devices that are located further away.

4.2. Thread Battery Operated Device

Thread Battery Operated Devices are devices on the network that generally only operate when requested, like light switches. They don't reroute data and can be sleepy devices to save energy, only to be activated and immediately become part of the Thread network upon use.

4.3. Thread Border Router

A Thread Border Router is the device that forms the link between the enterprise network, to the IEEE 802.15.4 energy-efficient wireless radio standard that is being used by Thread. It can be a dedicated device, or this functionality can be part of a powered device with another function. A Border Router does not need to convert data-packets, since Thread uses the same IPv6 protocol as the enterprise network, making Thread Border Routers straightforward devices. Thread supports having multiple Border Routers on the same network that dynamically take over the function, so there's no single point of failure. Manufacturers of wireless base stations offer products that combine Wi-Fi and Thread radios in a single device, even further reducing the complexity of extending an enterprise network with a secure and wireless network for low-power devices.

Requires Thread Border Router
Thread Mesh Extender Devices and Thread Battery Operated Devices require at least one Thread Border Router if they want to become part of a network outside of the Thread mesh itself, such as the building's IP infrastructure. To remind users of this, many devices carry a "Requires Thread Border Router" badge.

4.4. Building Automation Standards

Indicated in the picture with different numbers of dots, various Building Automation Standards can be used on a Thread network. As with other IP-based applications and devices (like printers, servers or copiers), multiple application types (like lighting, access control or climate systems) can share that same network, and these applications can be based on different protocols, like DALI+, KNX IoT or Matter.

4.5. Building Management System

A Building Management System (BMS) may be part of the enterprise network. Such a BMS can directly address each individual Thread device, as Thread's IPv6 connectivity is fully transparent to the existing enterprise network. Likewise, authorized PCs, laptops and mobile devices like smartphones and tablets are directly connected to the enterprise network and can also immediately access Thread devices using the existing IPv6 networking protocol.

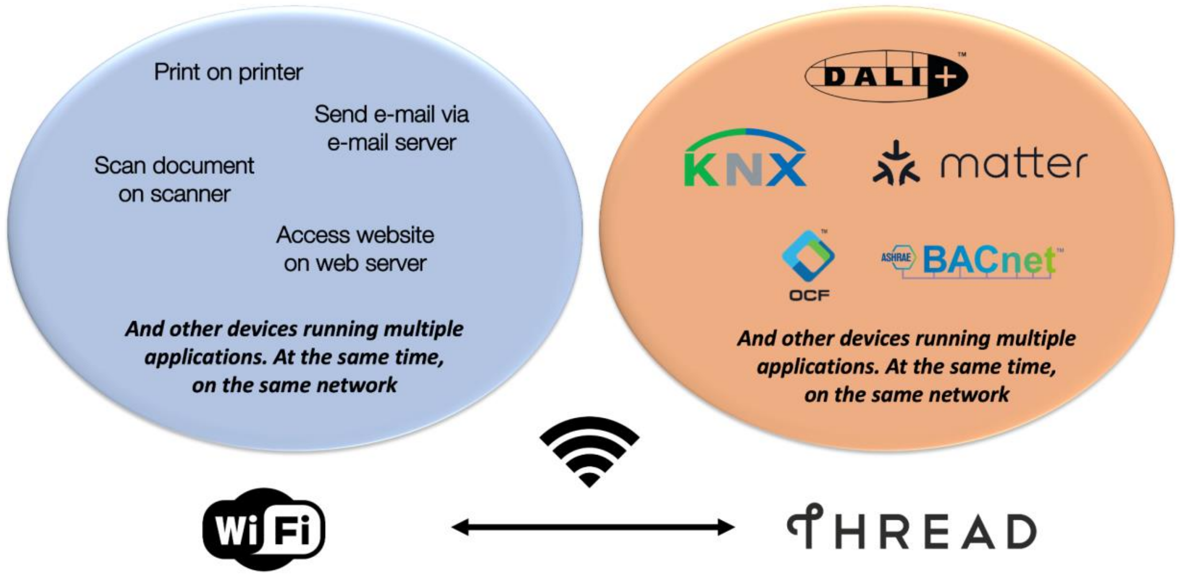
4.6. Cloud Connection

IP makes the life of system maintainers and IT staff much easier. All devices, including those on the Thread wireless mesh, can be remotely configured and maintained using familiar tools and technologies. It offers easy remote control, data collection and monitoring from anywhere in the world, while maintaining full end-to-end encryption.

4.7. Bridge to Traditional Non-IP Systems

Many buildings have legacy building automation systems in place that will only over time make the full transition to IP to unlock the many benefits as described above. They are either based on other physical network standards or non-IP based application protocols. These systems can be integrated with the rest of the network by means of a gateway that allows access to the respective network technology and application protocol.

5. Thread Supports Multiple Application Layers



Thread's application support is comparable to the way Wi-Fi works with multiple applications. By simply joining one Wi-Fi network, due to the common Internet Protocol we can access every service, regardless of who is offering it or from wherever it is being provided.

Today's wide offering of IoT solutions often require that we set up and maintain a network for every protocol we want to use. This not only requires surveillance and maintenance to keep them up-and-running, but networks might also interfere with each other. Furthermore, since they are separate networks, devices do not "talk" to each other and there is no way to control them effectively from a single location, monitor and analyze their data, or provision them over various locations and users, in an end-to-end secure manner.

This is where Thread comes in. Like Wi-Fi, it can run every modern IoT application that runs over IP, using a common physical network.

Having one single network for all your IoT devices provides major benefits. These devices do not interfere with each other, but instead can work together to extend the reach of the network by forming a mesh. Since the entire network is IPv6-based and does not need "conversion" of application data, encryption of data packets remains intact throughout the entire chain, all the way from the individual device up to the cloud. Every device is uniquely addressable, making it easier for system administrators to commission them individually or as a group, and to flexibly change those arrangements. All devices can be managed and monitored from a single location, opening the possibility for powerful data analysis.

What's more, Thread is designed so that in networks consisting of devices that use different application protocols, all these benefits remain in effect. Thread can run multiple application layers concurrently on the same network. This is simply not possible with other IoT solutions on the market today. If you use multiple devices based on different systems, all devices require their own network which often creates maintenance issues. And if in the future you want to replace or add an application layer, you need to replace the underlying wireless network. As with Wi-Fi, Thread allows you to simply start using the new application on the existing network.

All popular IoT-standards for building automation control recognize the importance of moving towards a universal, secure and interoperable IPv6-based network. And most of them have chosen Thread to be their future-proof solution. This includes DALI+, KNX IoT, Matter, OCF and BACnet. And since Thread is fully agnostic to the application layer, it is even possible to design and develop a custom application layer to suit specific needs (e.g. for unique factories and machinery, or medical applications).

Application standards will continue to focus on compelling new use cases, satisfying new IoT application requirements, and interoperability aspects between different applications on the same network.

Instead of developing yet another IoT protocol, Thread combines current and proven Internet-based technologies into a standard that's optimized for security and mesh networking in low-cost, low-power devices. Thread is transparent to the applications that run on the network which makes it the only future-proof choice for modern IP-based networks for IoT devices.

6. IPv6 Thread Networks in an IPv4-Based Enterprise Network

When defining requirements for building automation, network designers want to make sure that their solution operates well within the existing network. At the same time, they need assurance that the solution is both future proof and scalable. This is also true for developers defining smart products for the home.

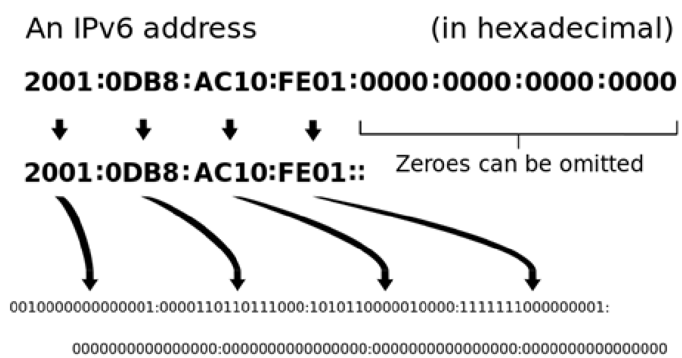
Thread is based on existing and widely deployed standards, like IPv6, and has been specifically designed for technologies that provide long-term deployment. Due to its extremely large addressing space, IPv6 allows every single device to have its own unique address which has not been possible before.

IPv6 is the successor to IPv4, the "legacy" internet protocol. IPv4 is known for its xxx.xxx.xxx.xxx addressing structure, where xxx can be a number between 1 and 255. With IPv4, approximately 4 billion unique addresses are possible, which is not nearly enough to cover every device on the planet.

To overcome the limitations of IPv4, local networks (including enterprise networks) use a technology called NAT (Network Address Translation) to act as an agent between the local network and the public Internet. NAT-functionality is included in a single device such as a router, allowing one IPv4 address to represent a larger group of computers to the outside network.

However, this form of address translation has several limitations which do not solve all the issues that arise due to IPv4's limited addressing-range. This is why IPv6 was developed.

IPv6 allows for 340,282,366,920,938,000,000,000,000,000,000,000,000 IP addresses. In addition to the extended addressing space, IPv6 adds several other benefits while fixing some shortcomings of IPv4. It has built-in Quality-of-Service allowing delay-sensitive packets to get priority in the data transfer, and includes automatic address configuration by default - eliminating complicated manual address assignment. And its improved header structure results in less processing overhead.



More and more Internet Service Providers and enterprise networks support IPv6. For these networks, Thread can be integrated simply without the need for address translation. For networks that still run on the legacy IPv4 protocol, some adaptations are needed. Luckily, much of this is handled by the Thread Border Router(s) which is the wireless access point that connects the Thread network to the enterprise network and thus also to the cloud.

Thread defines an IPv6 transport over an IEEE 802.15.4 data-link layer. A 6LoWPAN adaptation layer in between implements IPv6 header compression to maximize efficiency. In the context of the OSI layers, only the network layer is affected where IPv4 networks are used, as all of the other layers are fully transparent to the existing network.

A Thread Border Router is a function of a powered Thread device that connects the Thread wireless network to the rest of the enterprise network. Unlike "gateways" found in many wireless solutions, it is fully transparent to the transport and application protocols that reside above the network layer. As a result, applications can communicate securely from end-to-end without any application-layer translation. Furthermore, since Border Routers do not maintain any application-layer state, there can be multiple Border Routers in a network, eliminating a "single point of failure" in the event one of them malfunctions.

The Border Router enables every Thread device to directly connect to global cloud services, when enterprise networks run IPv6 and IPv4, or IPv4 only.

So how can a Thread network connect to an IPv4 network? A Thread Border Router typically handles all the requirements. A Border Router is not required to form a local Thread mesh-network. It is required to connect a Thread network to the outside world via the local home or enterprise network.

Typically, Border Routers implement NAT64 communication between IPv6-based Thread devices and IPv4 networks. NAT64 translates IPv6 packets to IPv4 and vice versa. The Border Router functions as an IPv4 host on the wide-area network, capable of obtaining an IPv4 interface and router address. It will acquire an address using DHCP from an IPv4 address pool. The Border Router may also implement Port Control Protocol (PCP) to control how incoming IPv4 packets are translated and forwarded and support static mappings.

Most of the IPv4 to IPv6 (and vice versa) translations can be handled by the Thread Border Router, with minimal changes needed to the existing network. This means that Thread can be immediately implemented in current working situations, while ensuring that the Thread network is ready for the future: when the time comes for a partial or full transition to IPv6.

7. Key Points and Conclusion

In summary, the main advantages of Thread for Smart Buildings are:

- IPv6 based
- Low power, self-healing mesh
- Centralized commissioning and operation
- Easy migration from traditional building automation towards true IP systems

In the ever-expanding universe of IoT applications, Thread Group sees great market opportunity in the smart building sector—and more specifically, the building automation, energy management and lighting control markets.

Thread's global membership, and the various industry alliances with which Thread collaborates with, are committed to standardizing on a common, cost-effective, secure, IP-based mesh networking infrastructure that supports interoperability for resource-constrained devices. With an established base as the leading IP mesh networking protocol in the residential IoT space, Thread is ready to scale from residential to large businesses and is well positioned to provide a strong foundation for robust and secure wireless networks in critical building infrastructures.

Thread delivers the features and functionality required by the building automation market in the smart building and Small Office/Home Office segments. As the standard for smart buildings, Thread is a cost-effective, reliable, secure, scalable mesh IP solution that is essential for any automated building system. With Thread's incorporation of next-generation IPv6 and low-power technologies, the groundwork is laid for an open, routable IPv6 mesh network infrastructure with end-to-end security for the connected building. Thread 1.2 adds capabilities to align the Thread specification with enterprise-level security, IT requirements, and user permissions, as well as capacity for very large managed networks.

Thread allows building owners to create an effective open network infrastructure that will not only support the heterogeneous devices and applications of today but, as with the internet at large, the heterogeneous devices and applications of tomorrow that will develop and evolve over time, all operating on the same IP network.