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Compression of internet protocol version 6 addresses in wireless sensor networks

Abstract

A method for managing Internet Protocol Version 6 (IPv6) addresses in a wireless sensor network is provided that includes storing, on a wireless sensor device in the wireless sensor network, a prefix of an IPv6 address in association with a key, forming an address indicator for the IPv6 address, the address indicator consisting of the key and a node address of the IPv6 address, and storing the address indicator in at least one memory location on the wireless sensor device in lieu of the IPv6 address.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/330,715, filed May 25, 2021, which is a continuation of U.S. patent application Ser. No. 14/836,655, filed Aug. 26, 2015 (now U.S. Pat. No. 11,051,140), which claims the priority benefit of U.S. Provisional Patent Application No. 62/053,002, filed Sep. 19, 2014, which applications are incorporated herein by reference.

BACKGROUND OF THE DISCLOSURE
Field of the Disclosure
(1) Embodiments of the present disclosure generally relate to wireless sensor networks, and more specifically relate to compression of Internet Protocol Version 6 (IPv6) addresses in such networks.
Description of the Related Art

(2) Wireless sensor networks are being deployed in many different environments. The sensors used in such networks are typically low cost devices with limited storage, computation, and power. The primary function of these devices is generally data acquisition, with an attendant function of communicating the acquired data over a wireless network. The typical architecture of these devices includes a microcontroller, memory on the order of magnitudes of tens of kilobytes split into read-only-memory and random access memory, a low power radio device, and power management circuitry. Given the limited memory capacity of these devices, conservation of memory usage is important.

SUMMARY

(3) Embodiments of the present disclosure relate to methods, apparatus, and computer readable media for management of IPv6 addresses in a wireless sensor network. In on aspect, a method for managing Internet Protocol Version 6 (IPv6) addresses in a wireless sensor network is provided that includes storing, on a wireless sensor device in the wireless sensor network, a prefix of an IPv6 address in association with a key, forming an address indicator for the IPv6 address, the address indicator consisting of the key and a node address of the IPv6 address, and storing the address indicator in at least one memory location on the wireless sensor device in lieu of the IPv6 address.

(4) In one aspect, a wireless sensor device is provided that includes a memory storing software instructions for managing Internet Protocol Version 6 (IPv6) addresses, and a processor configured to execute software instructions, in which execution of the software instructions stores a prefix of an IPv6 address in association with a key in the memory, forms an address indicator for the IPv6 address, the address indicator consisting of the key and a node address of the IPv6 address, and stores the address indicator in at least one location in the memory in lieu of the IPv6 address.

(5) In one aspect, a non-transitory computer readable medium storing software instructions is provided. The software instructions, when executed by a processor of a wireless sensor device in a wireless sensor network, cause a method for managing Internet Protocol Version 6 (IPv6) addresses to be performed. The method includes storing, on a wireless sensor device in the wireless sensor network, a prefix of an IPv6 address in association with a key, forming an address indicator for the IPv6 address, the address indicator consisting of the key and a node address of the IPv6 address, and storing the address indicator in at least one memory location on the wireless sensor device in lieu of the IPv6 address.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Particular embodiments will now be described, by way of example only, and with reference to the accompanying drawings:

(2) FIG. **1** is a simple example of an Internet Protocol Version 6 (IPv6) based wireless sensor network;

(3) FIG. **2** is an example illustrating an IPv6 address;

(4) FIG. **3** and FIG. **4** are examples illustrating, respectively, IPv6 address compression and IPv6 address decompression;

(5) FIG. **5** illustrates the operation of the IPv6 address compression and decompression in the context of an example network protocol stack; and

(6) FIG. **6** is a simplified block diagram of an example wireless sensor device.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE DISCLOSURE

(7) Specific embodiments of the disclosure will now be described in detail with reference to the accompanying figures. Like elements in the various figures are denoted by like reference numerals for consistency.

(8) FIG. **1** is a simple example of an Internet Protocol Version 6 (IPv6) based wireless sensor

network. In this example, the sensor devices labeled L-x are leaf nodes, the devices labeled Int-x are intermediate nodes, and the device labeled RootNode is the root node of the network and operates as a gateway to the internet. The device to device wireless communication is indicated by the “lightning bolt” arrows between the devices. The intermediate nodes and the root node may be operable to route communication around the network. Each of the devices implements a network protocol stack for communicating over the wireless network using IPv6 addresses.

(9) IPv6 addresses are 128 bits long and may be presented in hexadecimal notation as “xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx” where each “x” represents a hexadecimal digit and each grouping of four digits represents two bytes, e.g., “0000:FFE0:0000:0003:FFFF:FFFF:FFFC:00FD”. Thus, storage of a full IPv6 address requires sixteen bytes of memory. A grouping of two hexadecimal digits of an IPv6 address may be referred to as an octet herein. The network protocol stack implementation may require that IPv6 addresses be stored in multiple locations, e.g., network table entries, on a device. Rather than storing a full IPv6 address, in embodiments of the disclosure, a device compresses the IPv6 address as described herein and stores the compressed version in the one or more multiple locations. When a full IPv6 address is needed for network communication, the device decompresses the compressed address as described herein.

(10) In an IPv6 address, a prefix of N high-order octets specifies a particular network and the remainder of the octets specifies addresses within that network. Thus, the addresses of each node in the network may have a common prefix of N octets. The size of the prefix is based on the address space requirements of the network. For example, as illustrated in the example of FIG. **2**, if the maximum number of nodes that can be addressed in a network is 256, the common prefix for a node address in that network is the 120 high-order bits, i.e., the high-order 15 octets. Further, the last octet uniquely identifies nodes in the network, i.e., is a node address.

(11) In some embodiments of the IPv6 address compression and decompression, the prefix for all IPv6 addresses within a wireless sensor network is assumed to be the high-order, i.e., top, 15 octets. FIG. **3** and FIG. **4** are examples illustrating, respectively, IPv6 address compression and IPv6 address decompression assuming that the prefix is the high-order 15 octets. Referring first to FIG. **3**, to compress an IPv6 address **300** on a sensor device, the fifteen octet prefix of the address is stored in a prefix table **302** in the memory of the sensor device. The index of the table entry where the prefix is stored serves as a key for identifying the prefix. If the prefix of an address is already stored in the prefix table, the key is returned. The 8-bit key and the last octet of the address are then concatenated to generate a 16-bit IPv6 address indicator **304** that is stored in any location on the device in which the full IPv6 address would be stored. In some embodiments, the last octet is the first eight bits of the address indicator and the key is the last eight bits of the address indicator; in other embodiments, this order is reversed. Note that rather than storing a 128-bit address in multiple locations, a sixteen bit address indicator is stored in the multiple locations, a savings of 112 bits per location.

(12) Referring now to FIG. **4**, to decompress the address indicator **304** on the sensor device, the compression cycle is reversed. The prefix key in the address indicator **304** is used to locate the associated prefix in the prefix table **302**. The identified prefix is concatenated with the last octet in the address indicator **304** to re-create the full IPv6 address **300**.

(13) The number of IPv6 addresses to be stored on a particular sensor device may vary. For example, in the network of FIG. **1**, in order to route sensor data out of the network, a leaf node may store the address of the associated intermediate node and the address of the root node. For example, leaf device L-12 may store the IPv6 address of intermediate device Int-11 and the IPv6 address of the RootNode device. However, because leaf device L-6 is not associated with an intermediate node, the device may only store the IPv6 address of the root node. In some embodiments, a leaf node may also be aware of neighboring nodes and may store the IPv6 address of these nodes. For example, in such embodiments, leaf device L-10 may store the IPv6 addresses of leaf devices L-9,

L-8, and L-7 as well as the IPv6 addresses of the intermediate device Int-3 and the RootNode device.

(14) An intermediate node performs routing functions for associated leaf nodes, and thus may need to store the IPv6 addresses of the associated leaf nodes and of the root node. For example, in the network of FIG. **1**, intermediate device Int-11 may store the addresses of associated leaf devices L-11 and L-12 and intermediate device Int-5 may store the address of intermediate device Int-11. The root node also performs routing functions and serves as a gateway to the Internet. In some embodiments, the root node may store the IPv6 address of all nodes in the network.

(15) As previously mentioned, devices in the wireless sensor network implement a network protocol stack. FIG. **5** illustrates the operation of the above described IPv6 address compression and decompression in the context of an example network protocol stack. The example network protocol stacks on the two devices **500**, **502** include an application layer **504**,**524**, a network layer **508**, **528**, a Media Access Control (MAC) layer **510**, **530**, and a physical (PHY) layer **512**, **532**. An IPv6 address management component **506**, **526** logically operates between the application layer **504**, **524** and the network layer **508**, **528** to compress IPv6 addresses to form address indicators prior to storage and to decompress address indicators to re-create full IPv6 addresses.

(16) The MAC layer **510**, **530** and the PHY layer **512**, **532** may operate according to the IEEE 802.15.4 and IEEE 802.15.4e standards for these layers. The IEEE 802.15.4 standard provides PHY and MAC layer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements. IEEE 802.15.4e specifies an enhanced MAC layer protocol for such networks. Detailed descriptions of these protocols may be found in IEEE Std. 802.15.4™-2011, “Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)” and IEEE Std. 802.15.4e™-2012, “Part 15.4 Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC sublayer.”

(17) The network layer **508**, **528**, also referred to as the Internet Protocol (IP) layer, provides functionality such as breaking data from the application layer **504**, **524** into packets or extracting data from incoming packets for use by the application layer **504**, **524**, populating packet headers with information such as source and destination addresses, providing mechanisms to discover and pair with other devices, supporting power savings, and enabling secure communication. The network layer **508**, **528** may operate according to the Internet Engineering Task Force (IETF) RFC1460 entitled “Internet Protocol, Version 6 (IPv6) Specification.” Additional information regarding using IPv6 in wireless sensor networks is available in IETF RFC4919 entitled “IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals.”

(18) The application layer **504**, **524** serves as an interface between software operating on the device **500**, **502** that sends and/or receives data on the wireless sensor network and the network layer **508**, **528**. This layer may contain any application operating on the device **500**, **502** that communicates with other networked devices.

(19) The example of FIG. **5** illustrates the flow of data from a sending wireless sensor device **500** to a receiving wireless sensor device **502**. This example assumes that a prefix table has been created on the device **500** and includes at least one prefix as previously defined herein. The example further assumes that any stored IPv6 addresses, such as the IPv6 addresses of the device **500** and wireless sensor device **502**, are stored in the address indicator format previously described herein.

(20) To transmit data, the application layer **504** provides the data to the network layer **508** in a format expected by the network layer **508**. The address indicators for any IPv6 addresses needed for transmitting the data to device **502** are decompressed by the IPv6 address management component **506** to re-create the IPv6 addresses and provided to the network layer **508**. Further, IPv6 addresses in various network tables maintained by the network layer **508** are stored in the address indicator format. These addresses are decompressed by the IPv6 address management

component **506** to re-create the IPv6 addresses corresponding to the original network table entries when needed by the network layer **508**. Decompression of address indicators is previously described herein.

(21) The network layer **508** breaks the data into one or more packets in which the IPv6 addresses are included in the header and provides the packets to the MAC layer **510**, which operates with the PHY layer **512** to transmit the one or more packets to device **502**.

(22) On device **502**, the received data passes through the PHY layer **532** and the MAC layer **530** and is provided to the network layer **528** in packet format. The network layer **528** processes the header information in each received packet and provides the data payloads to the application layer **524**. Any IPv6 addresses that need to be stored on device **502** and/or are to be processed in the application layer **524** and/or are to be stored in the network tables of the network layer **528** are compressed by the IPv6 address management component **526** to generate address indicators for the addresses. These address indicators are then stored and/or provided to the application layer **524** and/or the network layer **528**. Compression of IPv6 addresses to generate address indicators is previously described herein.

(23) FIG. **6** is a simplified block diagram of an example wireless sensor device **600** that may be deployed in a wireless sensor network such as the example network of FIG. **1** and may be configured to perform IPv6 address management as described herein. More specifically, the example wireless sensor device **600** may be embodied as a CC26xx SimpleLink™ Multistandard wireless microcontroller (MCU) integrated circuit (IC) available from Texas Instruments. The CC26xx family of ultralow-power microcontrollers includes multiple devices featuring an ultralow power CPU and different peripherals targeted for various applications. The particular MCU depicted is the CC2650. A brief description of the CC2650 is provided herein. A detailed description of the CC2650 is provided in Texas Instruments publication SWRS158, “CC2650 SimpleLink™ Multistandard Wireless MCU,” February 2015, which is incorporated by reference herein.

(24) The MCU **600** incorporates a 32-bit ARM® Cortex®-M3 as the main processor and a peripheral feature set that includes an ultra-low power sensor controller for interfacing external sensors and/or collecting analog and digital data autonomously while the rest of the system is in sleep mode. The MCU **600** also incorporates an RF core based on an ARM® Cortex®-MO processor. The RF core is designed to autonomously handle time critical aspects of various radio protocols. The RF core includes a dedicated 40 KB static random access memory (SRAM) and a dedicated read-only memory (ROM).

(25) The MCU **600** also incorporates 128 KB of flash memory that provides nonvolatile storage for code and data, 20 KB of SRAM that can be used for both storage of data and execution of code, and a ROM storing a real-time operating system kernel and some lower layer protocol stack software such as 802.15.4 MAC software. General peripherals/modules on the MCU **600** may include a 12-bit A/D converter, a 16-channel comparator with voltage reference generation and hysteresis capabilities, interfaces for SPI, Microwire, and UART protocols, internal direct memory access (DMA), a real-time clock, multiple 16/32-bit timers, and more.

(26) Software instructions implementing network stack layers and the IPv6 address management described herein may be stored in a computer readable medium on the MCU **600** such as the flash memory, the SRAM, or the ROM on the MCU **600** and executed by the main CPU.

(27) Other Embodiments

(28) While the disclosure has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the disclosure as disclosed herein.

(29) For example, embodiments of IPv6 address compression and decompression have been described herein that assume the common prefix of an IPv6 address is the high-order 15 octets and the last octet is a unique node address. One of ordinary skill in the art will understand embodiments

in which the number of octets in the common prefix and the number of octets in the node address may differ. More generically, if there are M octets in a node address, then the common prefix is the (16-M) high-order octets. Thus, the prefix stored in the prefix table may be the high order (16-M) octets and the node address concatenated with the key to form an address indicator is the remaining lower order M octets. The example used to describe previous embodiments herein assumes M=1.
(30) Certain terms are used throughout the description and the claims to refer to particular system components. As one skilled in the art will appreciate, components may be referred to by different names and/or may be combined in ways not shown herein without departing from the described functionality. This document does not intend to distinguish between components that differ in name but not function. In the discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to . . . .”
(31) It is therefore contemplated that the appended claims will cover any such modifications of the embodiments as fall within the true scope of the disclosure.

Claims

1. A method comprising: determining, by a first device, a prefix of an address of a second device, wherein the address comprises N bits, N being a positive integer, wherein the prefix of the address corresponds to L most significant bits (MSBs) of the address, L being a positive integer higher than 1 and lower than N, and wherein P least significant bits of the address form a node address, wherein P is equal to N minus L; associating a key with the prefix, wherein the key comprises a first number of bits that is smaller than a second number of bits of the prefix; forming a compressed address by concatenating the key with the first node address; and storing a plurality of copies of the compressed address into a respective plurality of memory locations in the first device to form a plurality of stored copies of the compressed address.
2. The method of claim 1, further comprising storing the prefix in a table of the first device without storing the key in the table, wherein the key corresponds to an index of a table entry of the table in which the prefix is stored.
3. The method of claim 2, wherein the first device is a root node of a wireless sensor network.
4. The method of claim 2, wherein the table comprises S entries, wherein S is equal to P{circumflex over ( )}2.
5. The method of claim 4, wherein P is equal to 16, and S is equal to 256.
6. The method of claim 2, further comprising: retrieving the key from a stored copy of the compressed address of the plurality of stored copies of the compressed address; retrieving the node address from the stored copy of the compressed first address; retrieving the prefix from the table using the key as the index of the table; and concatenating the retrieved prefix with the retrieved node address to recreate the address.
7. The method of claim 6, further comprising providing the recreated address to a network layer of a network protocol stack of the first device.
8. The method of claim 1, wherein the first device is a wireless sensor device.
9. The method of claim 8, wherein the first device is a leaf node in a wireless sensor network.
10. The method of claim 9, wherein the second device is a root node of the wireless sensor network.
11. The method of claim 1, wherein the address is an 128-bit Internet Protocol Version 6 (IPv6) address.
12. The method of claim 11, wherein the prefix corresponds to an M-octet prefix of the 128-bit IPv6 address, wherein the node address corresponds to a (16-M)-octet of the 128-bit IPv6 address, and wherein M is a positive integer.
13. The method of claim 12, wherein M is equal to 1.

14. A wireless device comprising: a memory; and a processor configured to: determine a prefix of an address of a second device, wherein the address comprises N bits, N being a positive integer, wherein the prefix of the address corresponds to L most significant bits (MSBs) of the address, L being a positive integer higher than 1 and lower than N, and wherein P least significant bits of the address form a node address, wherein P is equal to N minus L; associate a key with the prefix, wherein the key comprises a first number of bits that is smaller than a second number of bits of the prefix; form a compressed address by concatenating the key with the node address; and store a plurality of copies of the compressed address into a respective plurality of memory locations of the memory to form a plurality of stored copies of the compressed address.
15. The wireless device of claim 14, wherein the processor is configured to store the prefix in a table without storing the key in the table, wherein the key corresponds to an index of a table entry of the table in which the prefix is stored.
16. The wireless device of claim 15, wherein the processor is configured to: retrieve the key from a stored copy of the compressed address of the plurality of stored copies of the compressed address; retrieve the node address from the stored copy of the compressed address; retrieve the prefix from the table using the key as the index of the table; and concatenate the retrieved prefix with the retrieved node address to recreate the address.
17. The wireless device of claim 16, wherein the processor is configured to provide the recreated address to a network layer of a network protocol stack of the wireless device.
18. The wireless device of claim 15, wherein the table comprises S entries, wherein S is equal to P{circumflex over ( )}2.
19. The wireless device of claim 14, wherein the wireless device is a wireless sensor device.
20. The wireless device of claim 14, wherein the address is an 128-bit Internet Protocol Version 6 (IPv6) address, wherein the prefix corresponds to an M-octet prefix of the 128-bit IPv6 address, wherein the node address corresponds to a (16-M)-octet of the 128-bit IPv6 address, and wherein M is a positive integer.