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Nix

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(54) **SYSTEMS AND METHODS FOR
“MACHINE-TO-MACHINE” (M2M)
COMMUNICATIONS BETWEEN MODULES,
SERVERS, AND AN APPLICATION USING
PUBLIC KEY INFRASTRUCTURE (PKI)**

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G06F 2221/2115; H04L 9/0841;
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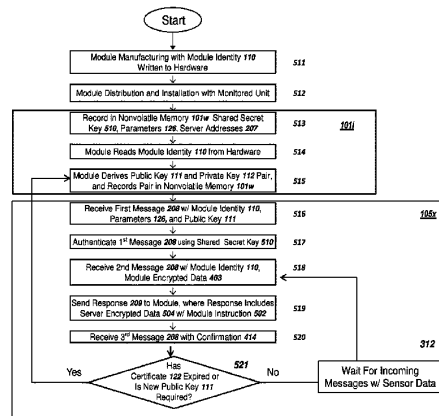
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(57) **ABSTRACT**

Methods and systems are provided for supporting efficient and secure “Machine-to-Machine” (M2M) communications using a module, a server, and an application. A module can communicate with the server by accessing the Internet, and the module can include a sensor and/or an actuator. The module, server, and application can utilize public key infrastructure (PKI) such as public keys and private keys. The module can internally derive pairs of private/public keys using cryptographic algorithms and a first set of parameters. A server can authenticate the submission of derived public keys and an associated module identity. The server can use a first server private key and a second set of parameters to (i) send module data to the application and (ii) receive module instructions from the application. The server can use
(Continued)



a second server private key and the first set of parameters to communicate with the module.

20 Claims, 17 Drawing Sheets

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(58) Field of Classification Search

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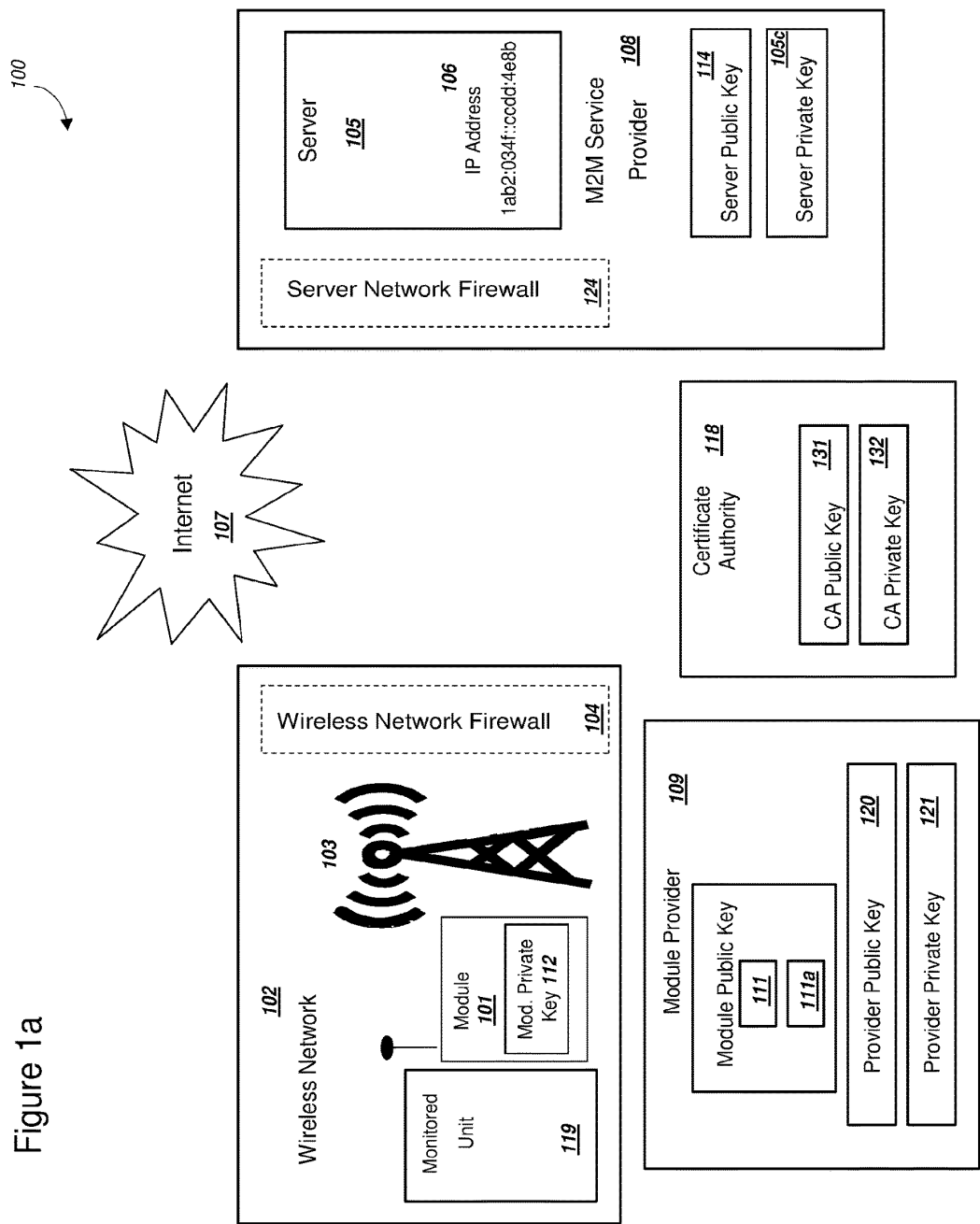


Figure 1d

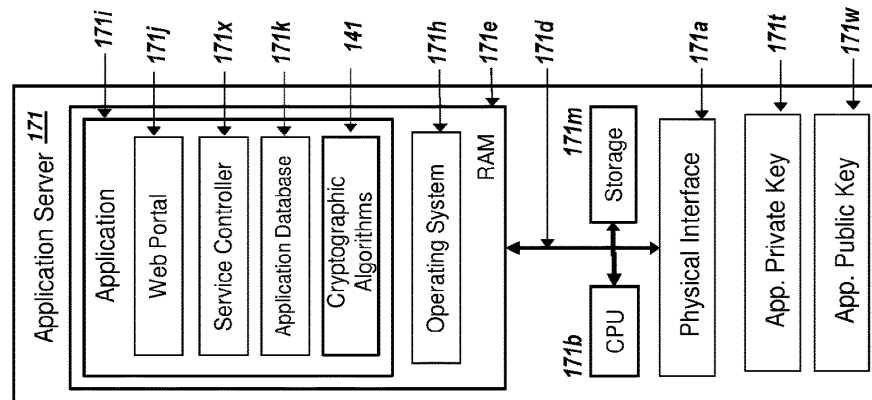


Figure 1c

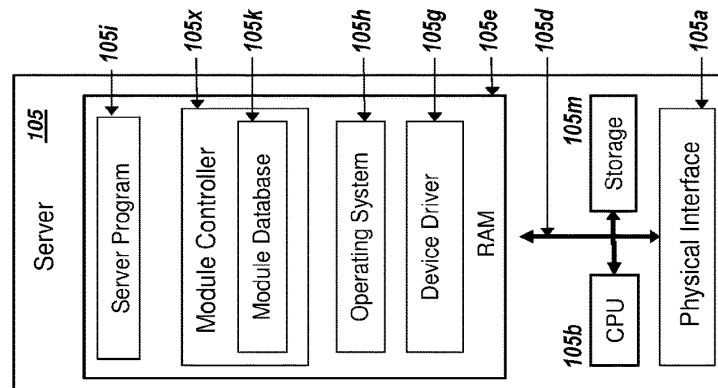


Figure 1b

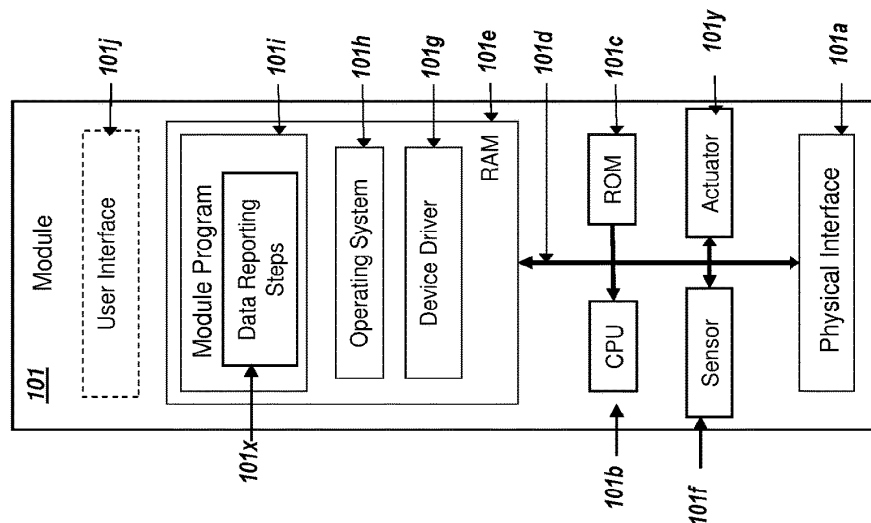


Figure 1f

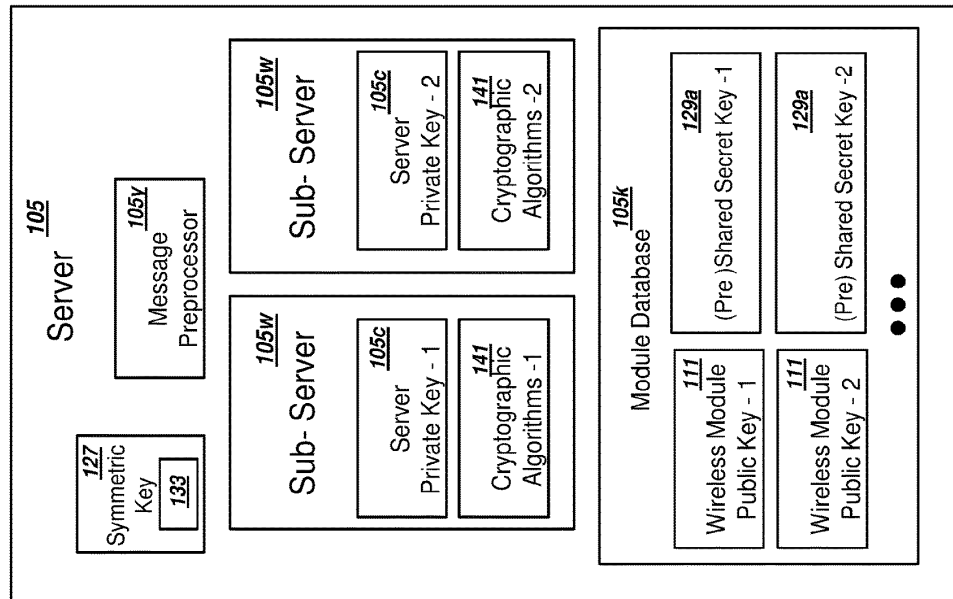


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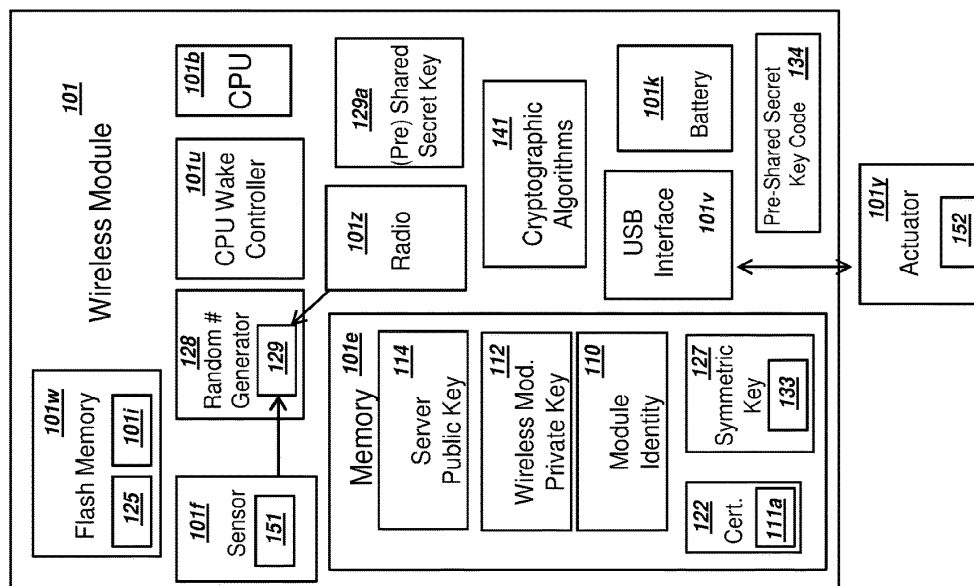


Figure 1g

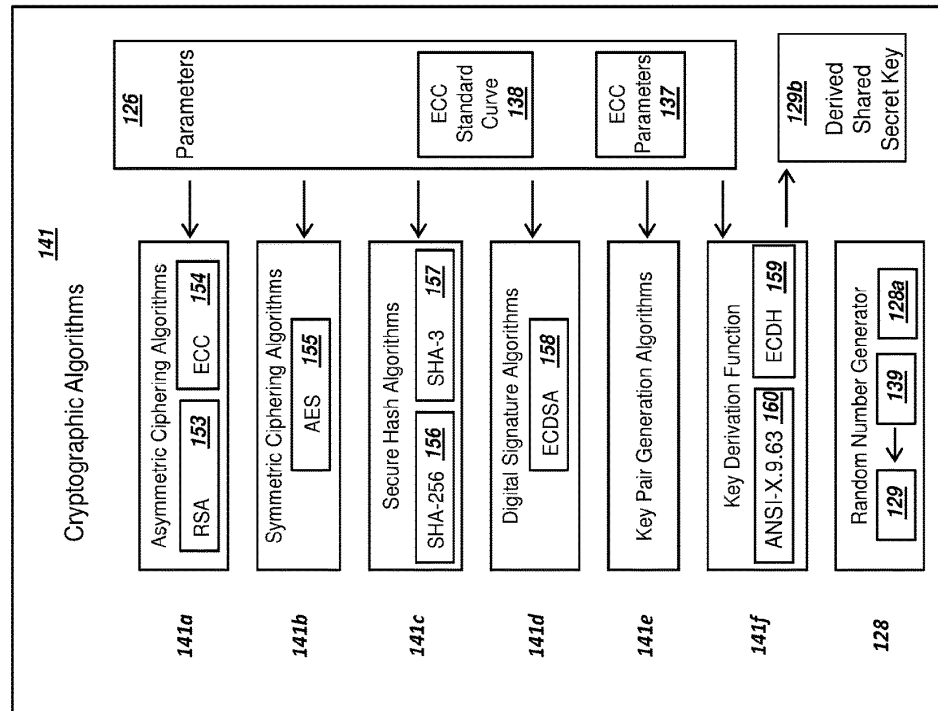
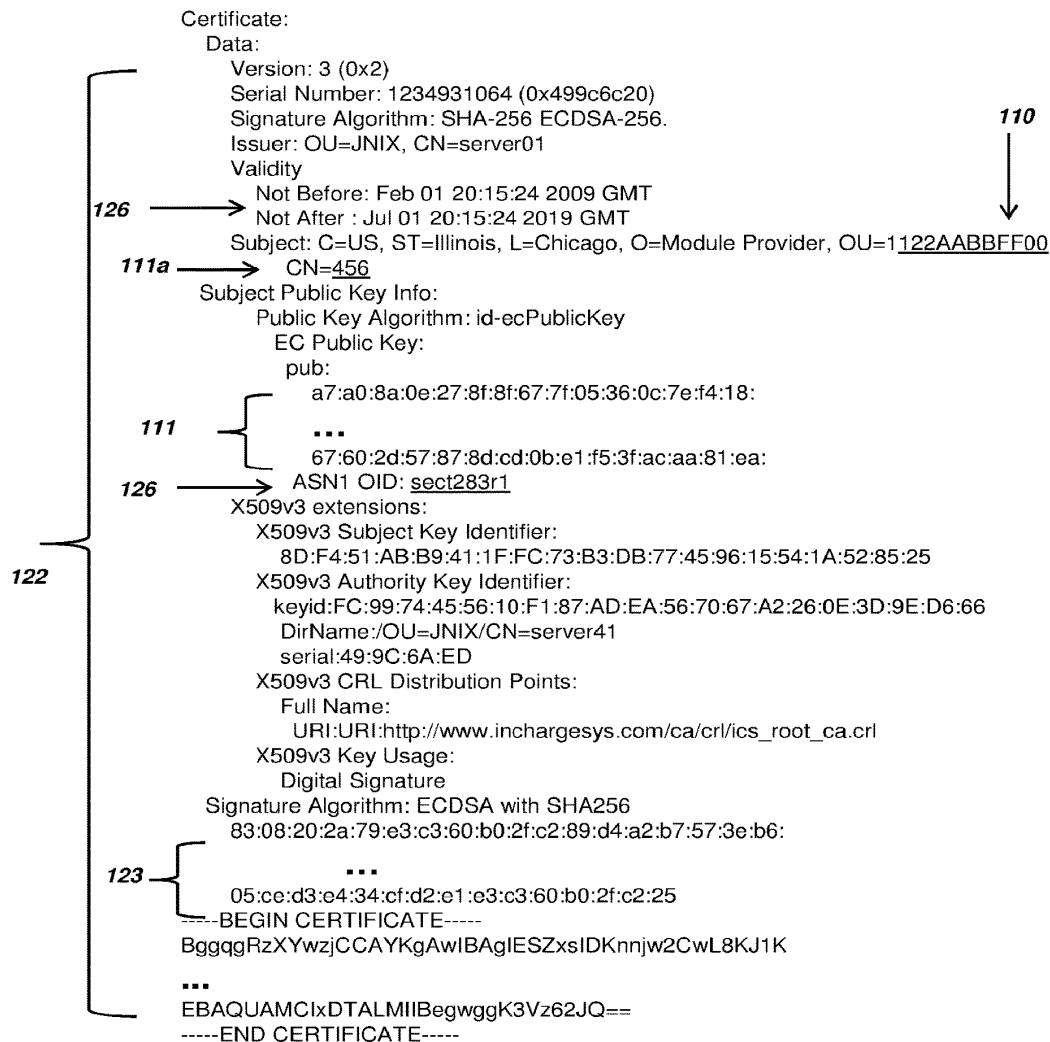
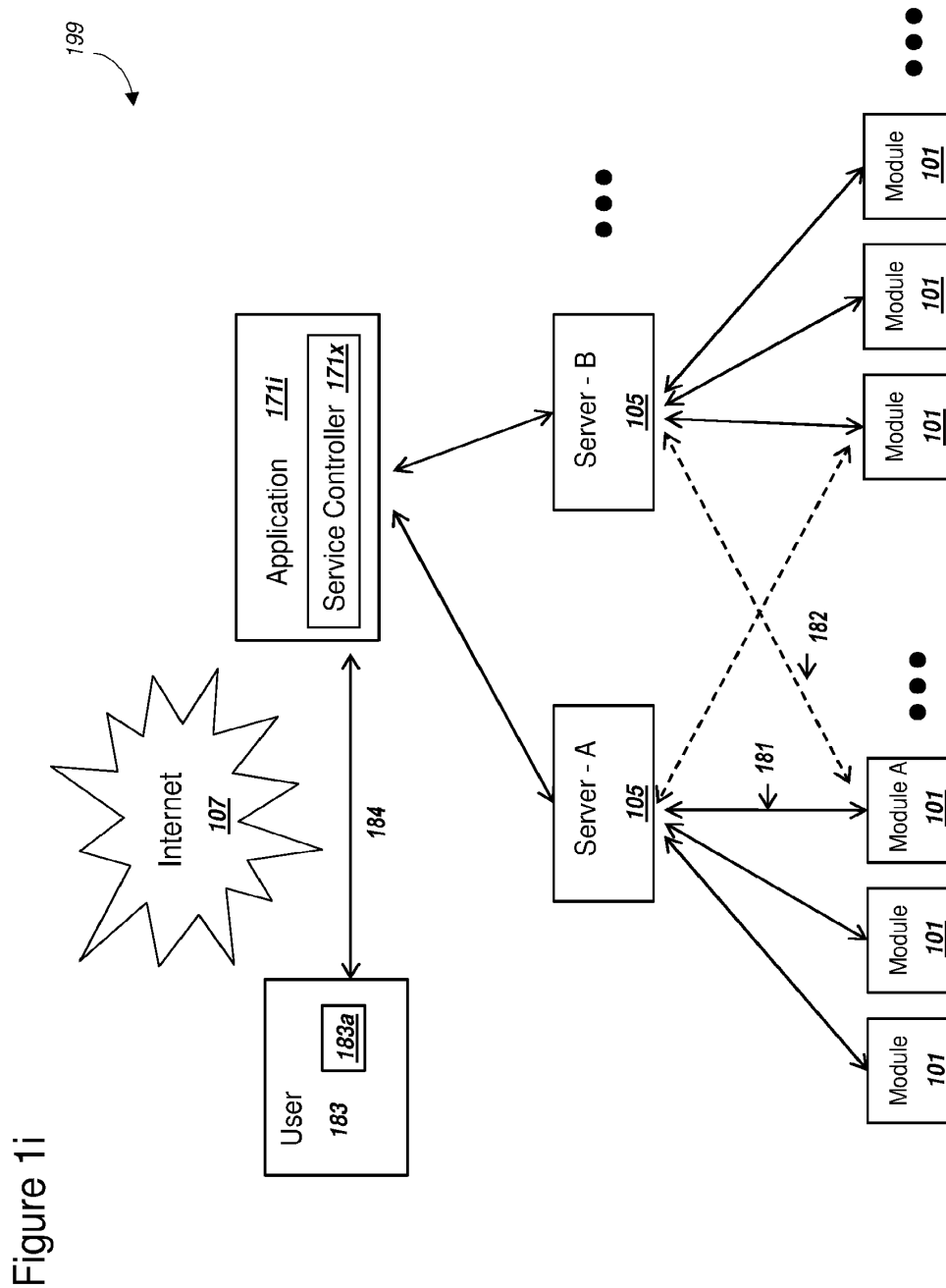
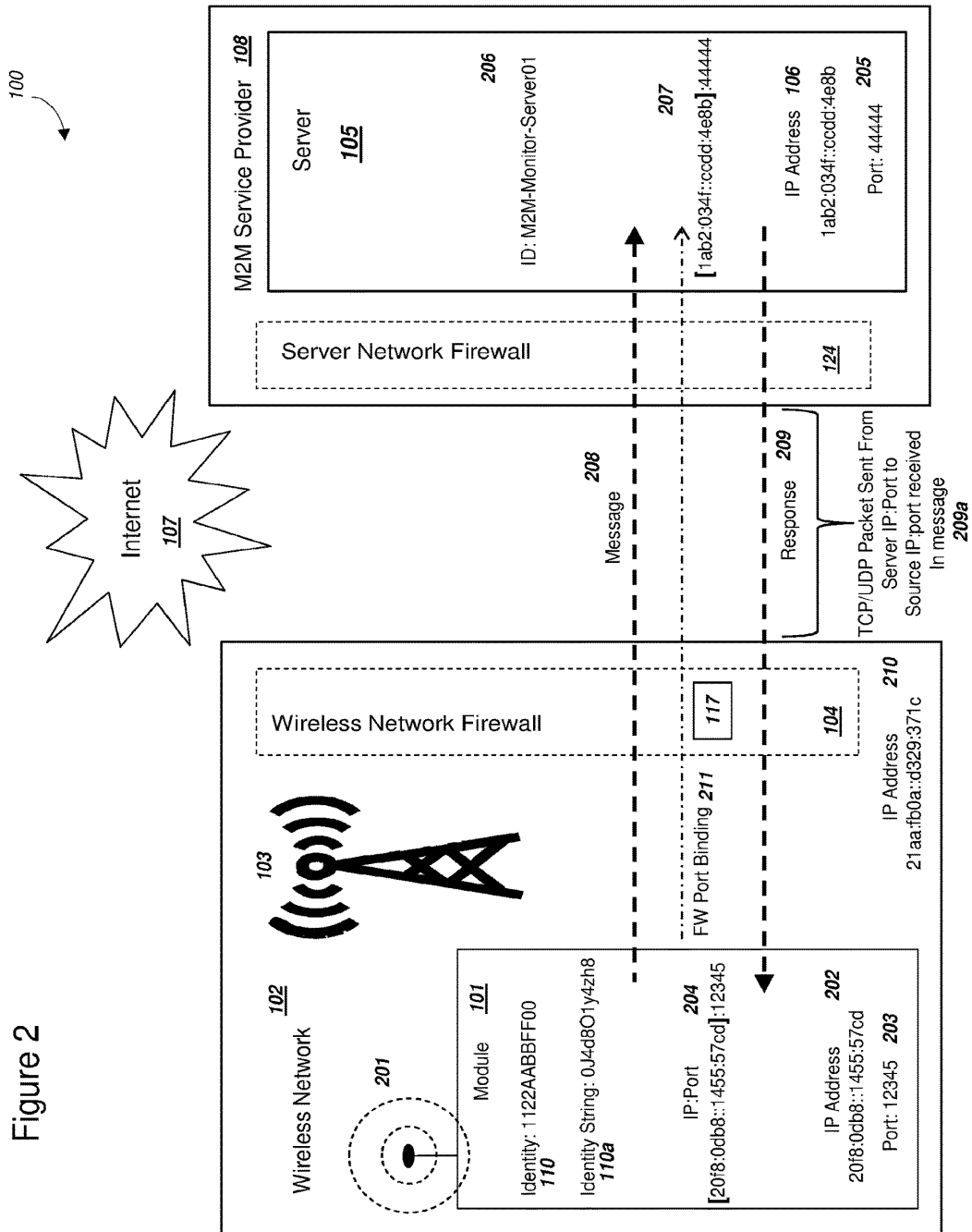


Figure 1h

283 bit Elliptic Curve Key with SHA 256 Signature ("... " is long text removed)







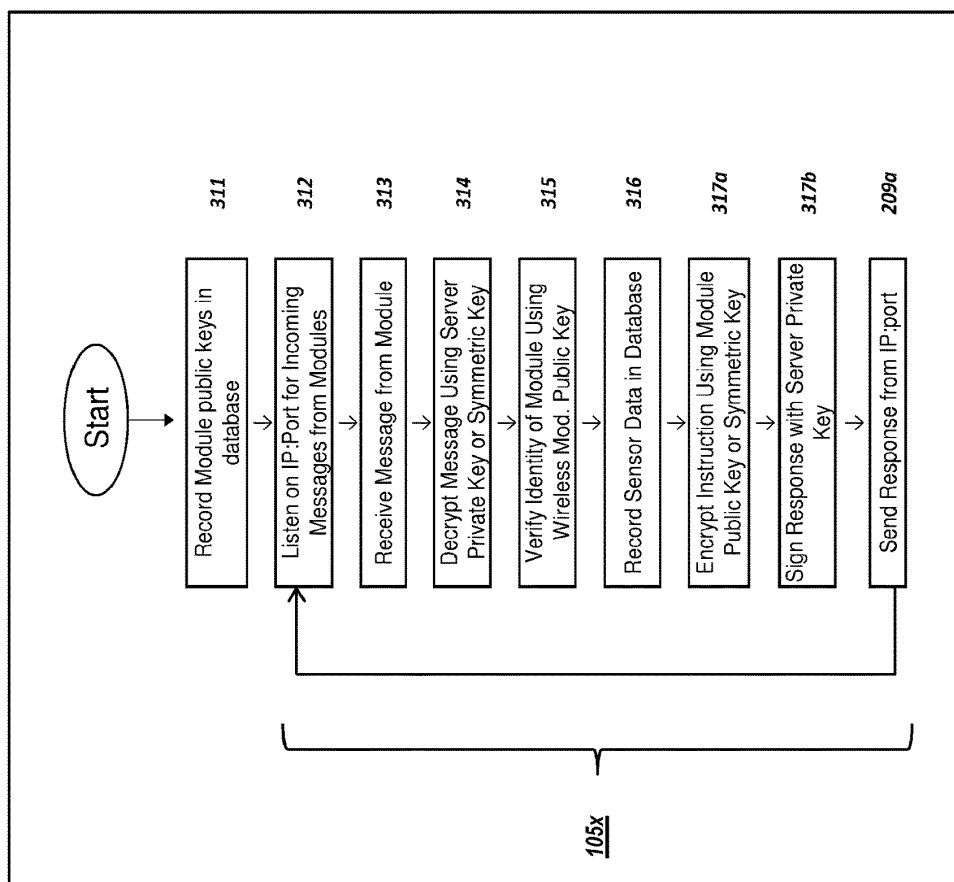


Figure 3

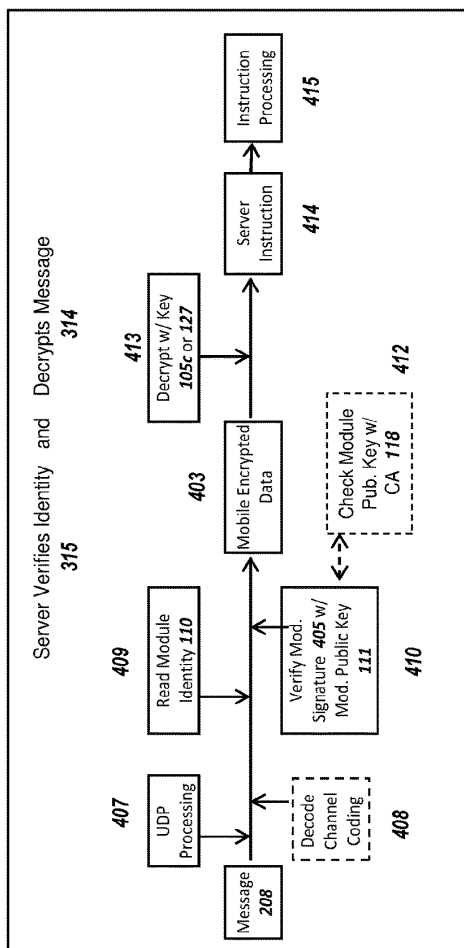


Figure 4

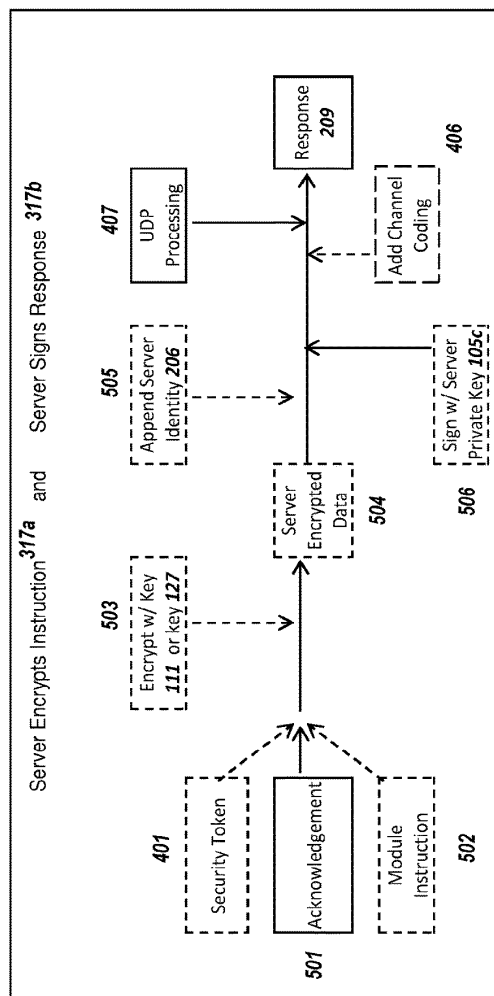
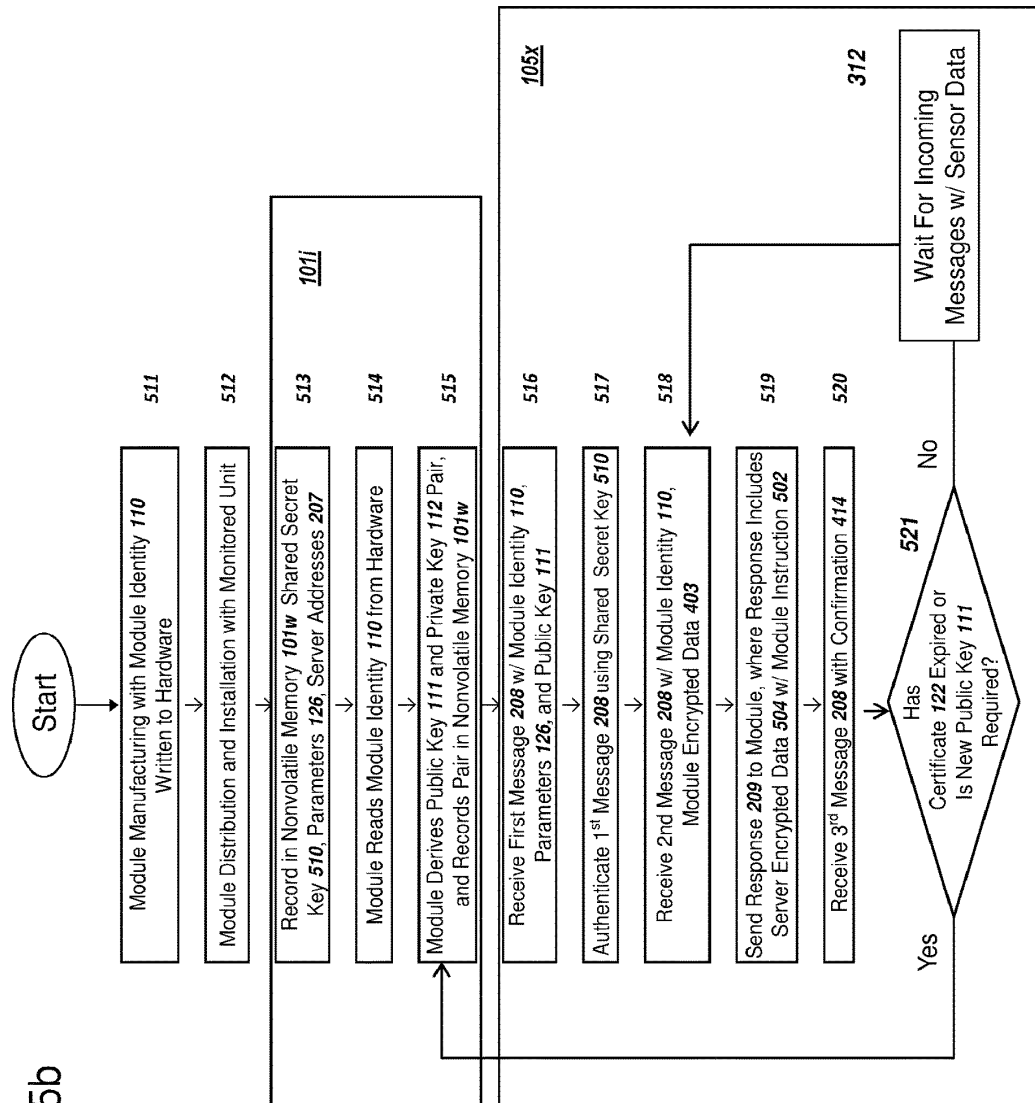


Figure 5a

Figure 5b



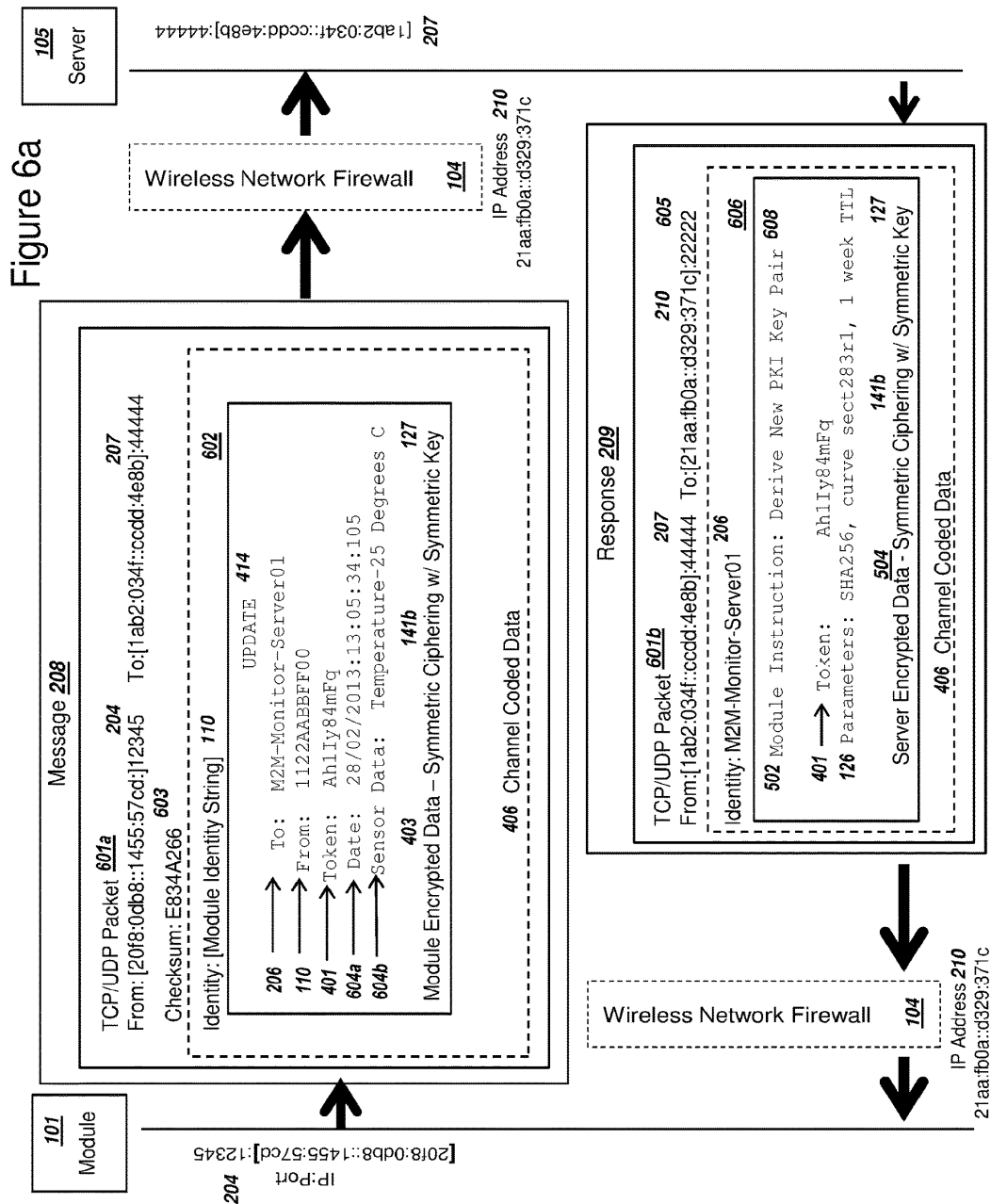
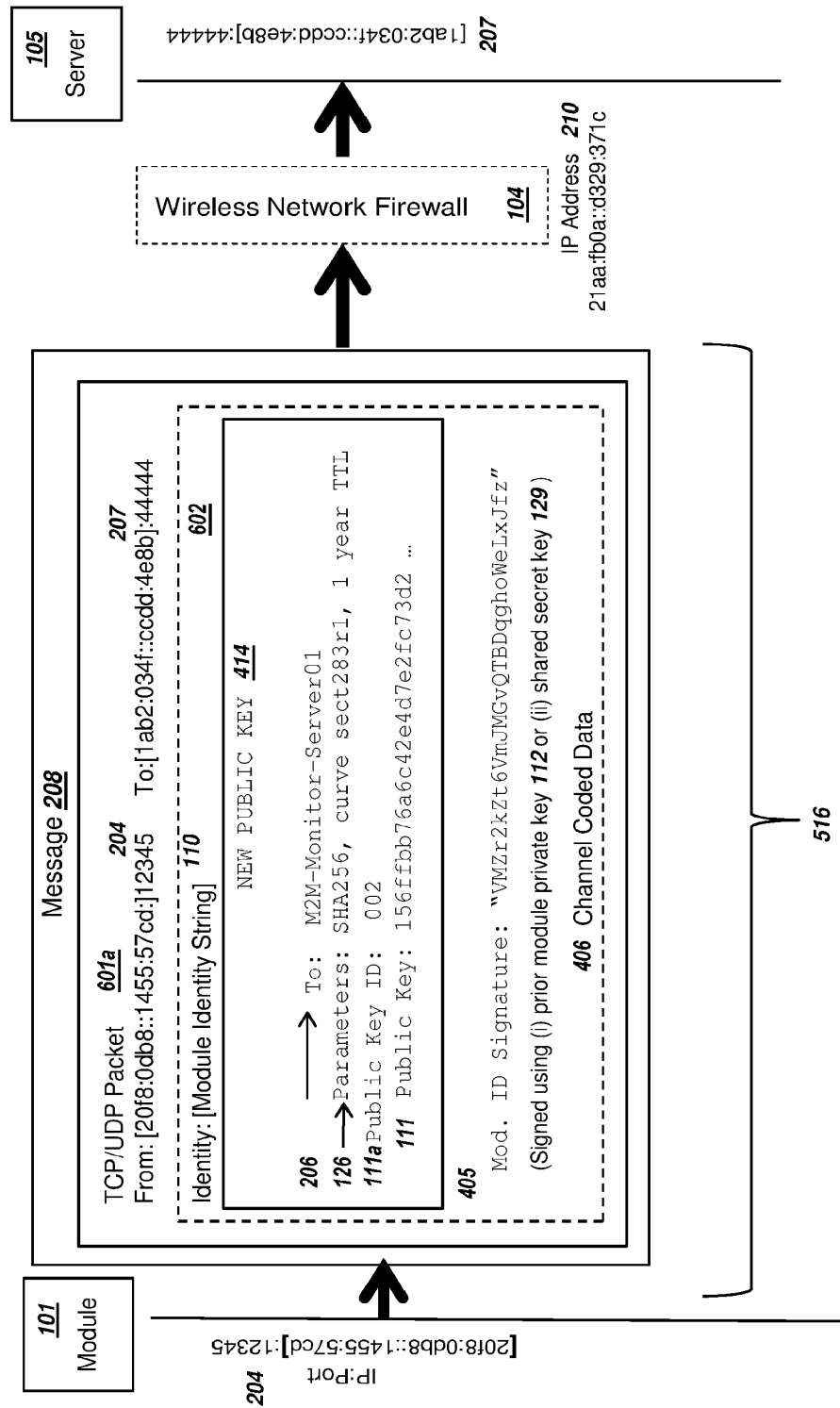


Figure 6b



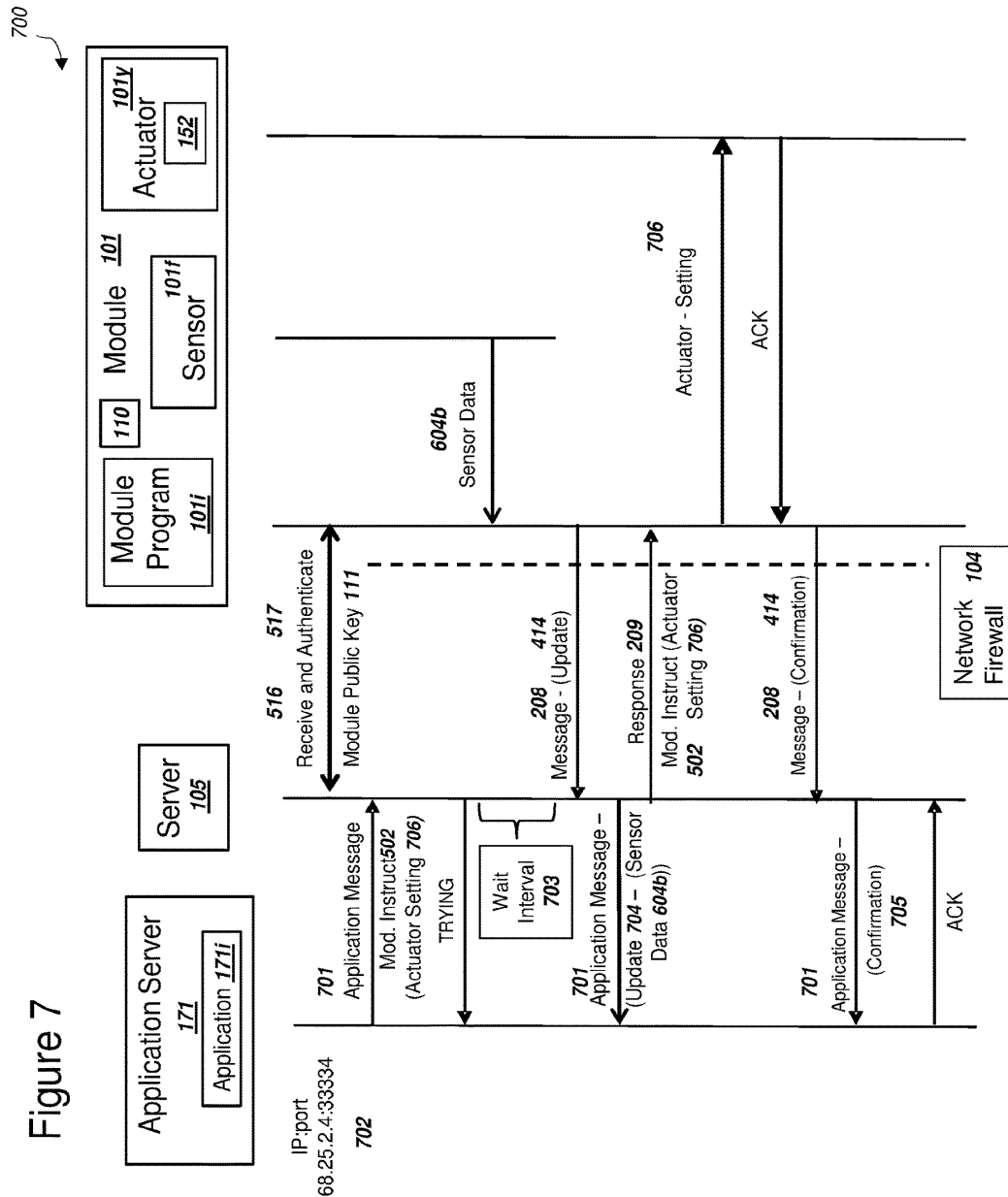
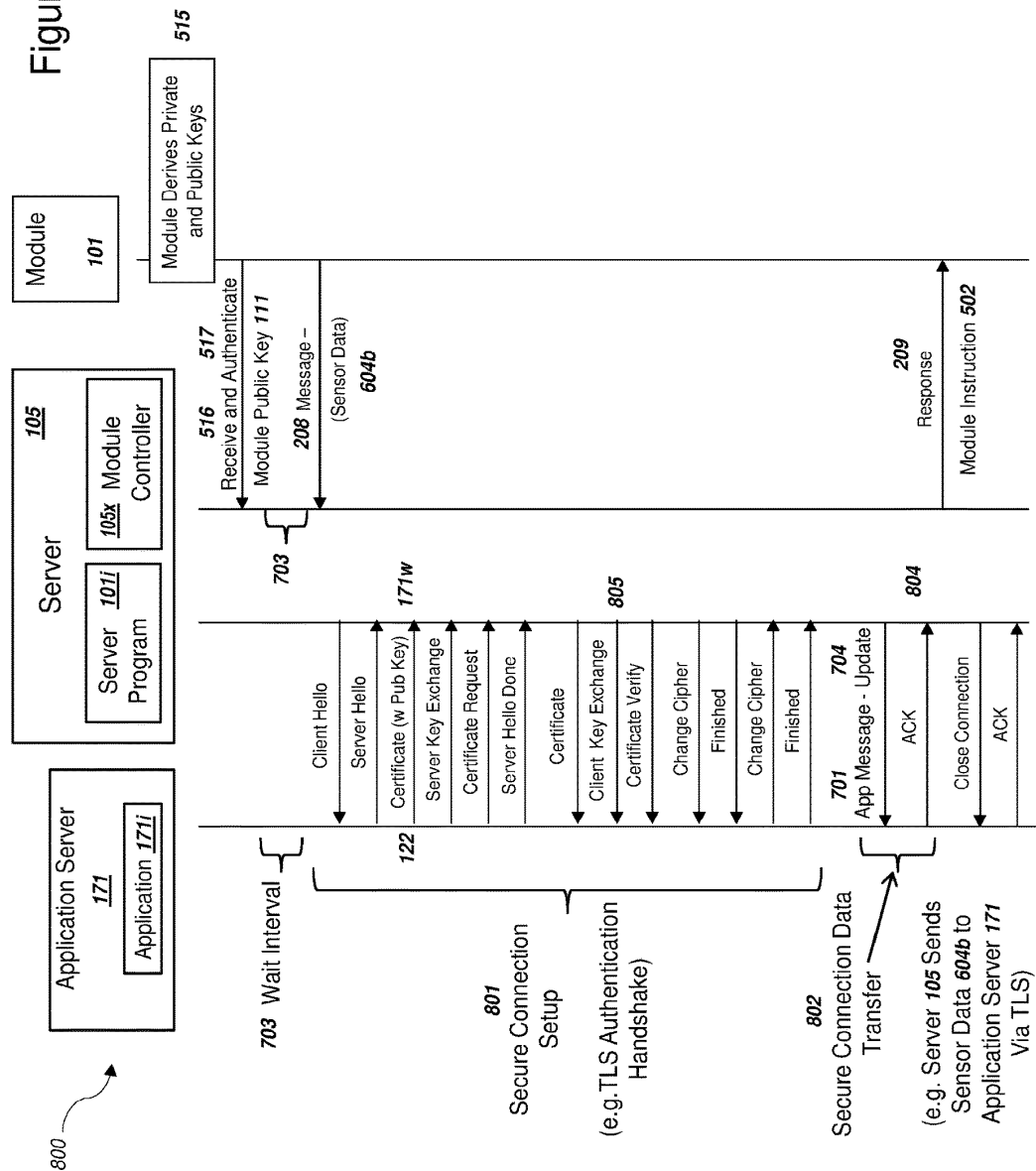


Figure 8



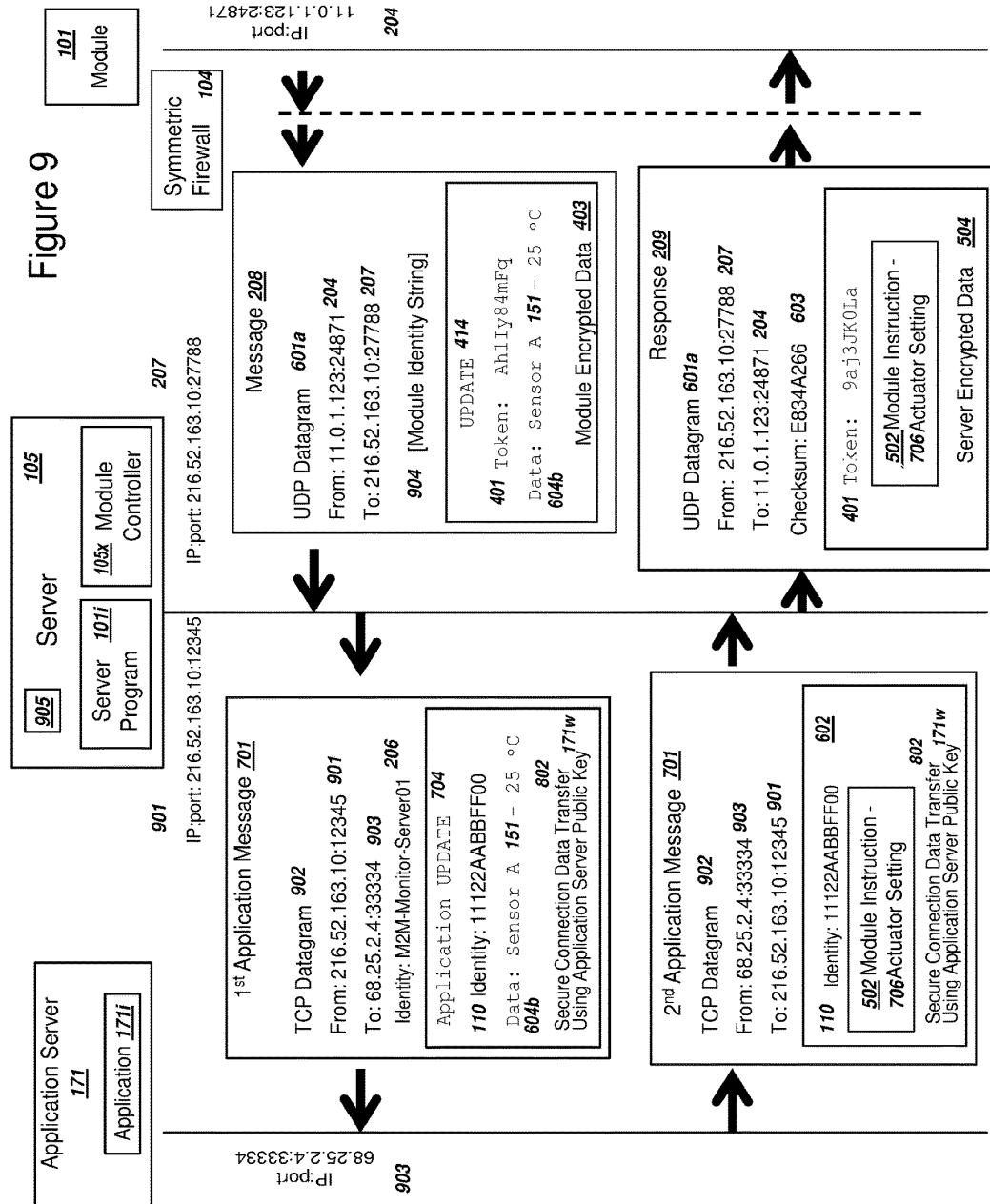


Figure 10

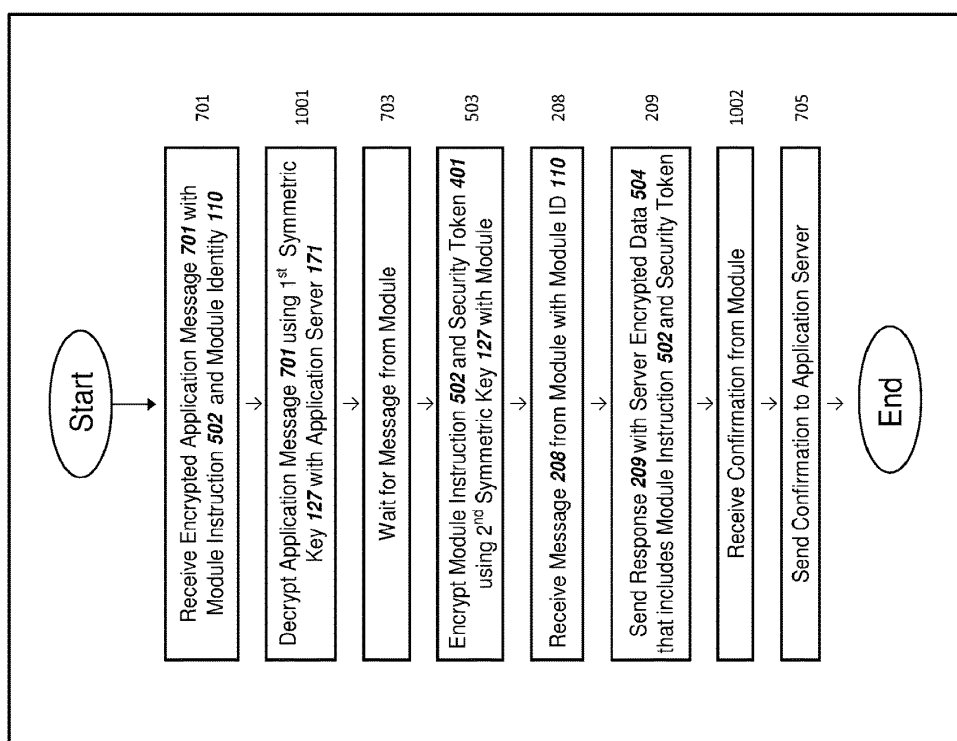
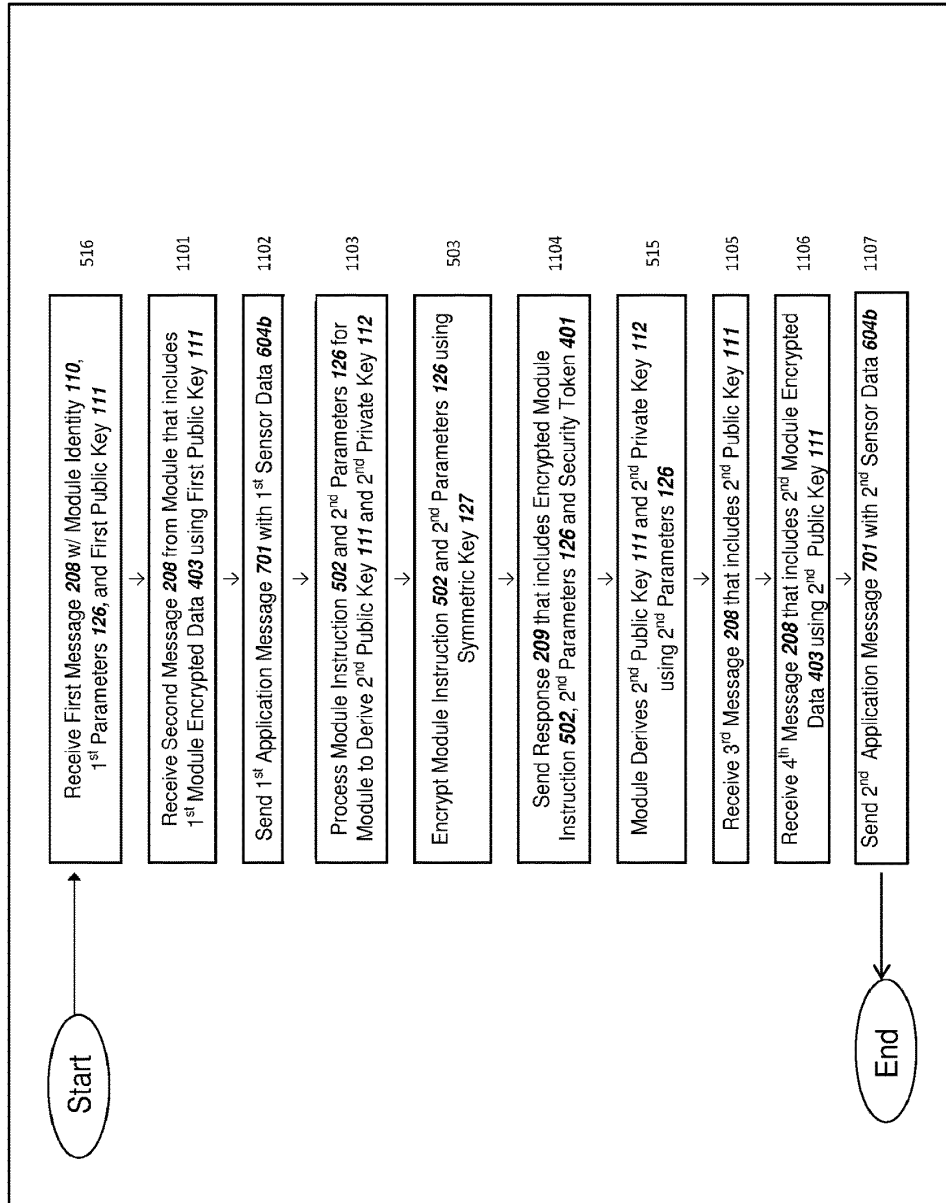


Figure 11



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**SYSTEMS AND METHODS FOR
“MACHINE-TO-MACHINE” (M2M)
COMMUNICATIONS BETWEEN MODULES,
SERVERS, AND AN APPLICATION USING
PUBLIC KEY INFRASTRUCTURE (PKI)**

**CROSS-REFERENCE TO RELATED
APPLICATIONS**

This is a continuation of U.S. patent application Ser. No. 16/593,561, filed Oct. 4, 2019, which is a continuation of U.S. patent application Ser. No. 16/036,506 filed Jul. 16, 2018, now U.S. Pat. No. 10,530,575, which is a continuation of U.S. patent application Ser. No. 15/583,968 filed May 1, 2017, now U.S. Pat. No. 10,057,059, which is a continuation of U.S. patent application Ser. No. 15/010,905 filed Jan. 29, 2016, now U.S. Pat. No. 9,641,327, which is a continuation of U.S. patent application Ser. No. 14/055,606 filed Oct. 16, 2013, now U.S. Pat. No. 9,276,740, each of which is fully incorporated by reference herein.

The subject matter of this application is related to the subject matter of U.S. patent application Ser. No. 14/023,181, filed Sep. 10, 2013, which issued as U.S. Pat. No. 9,350,550, in the name of John Nix, entitled “Power Management and Security for Wireless Modules in ‘Machine-to-Machine’ Communications,” which is hereby incorporated by reference in its entirety.

The subject matter of this application is also related to the subject matter of U.S. patent application Ser. No. 14/039,401, filed Sep. 27, 2013, which issued as U.S. Pat. No. 9,288,059 in the name of John Nix, entitled “Secure PKI Communications for ‘Machine-to-Machine’ Modules, including Key Derivation by Modules and Authenticating Public Keys,” which is hereby incorporated by reference in its entirety.

BACKGROUND

Technical Field

The present methods and systems relate to communications between wireless modules and a network, and more particularly, to efficient methods and systems for supporting secure, efficient, and flexible communications using Internet Protocol networks, where a server can communicate with both a “machine-to-machine” modules and an application.

Description of Related Art

The combination of “machine-to-machine” (M2M) communications and using low-cost sensors, Internet connections, and processors is a promising and growing field. Among many potential benefits, M2M technologies allow the remote monitoring of people, assets, or a location where manual monitoring is not economic, or costs can be significantly reduced by using automated monitoring as opposed to manual techniques. Prominent examples today include vending machines, automobiles, alarm systems, and remote sensors. Fast growing markets for M2M applications today include tracking devices for shipping containers or pallets, health applications such as the remote monitoring of a person’s glucose levels or heartbeat, monitoring of industrial equipment deployed in the field, and security systems. Many M2M applications leverage either wired Internet connections or wireless connections, and both types of connections continue to grow rapidly. M2M applications may also be referred to as “the Internet of things”.

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M2M communications can provide remote control over actuators that may be connected to a M2M device, such as turning on or off a power switch, locking or unlocking a door, adjusting a speed of a motor, or similar remote control.

A decision to change or adjust an actuator associated with an M2M device can utilize one or a series of sensor measurements. An M2M device may also be referred to as a “wireless module” or also simply a module. As one example, if a building or room is too cold, then temperature can be reported to a central server by an M2M device and the server can instruct the M2M device to turn on a switch that activates heat or adjusts a thermostat. As the costs for computer and networking hardware continue to decline, together with the growing ease of obtaining either wired or wireless Internet access for small form-factor devices, the number of economically favorable applications for M2M communications grows.

Many M2M applications can leverage wireless networking technologies. Wireless technologies such as wireless local area networks and wireless wide area networks have proliferated around the world over the past 15 years, and usage of these wireless networks is also expected to continue to grow. Wireless local area network (LAN) technologies include WiFi and wireless wide area network (WAN) technologies include 3rd Generation Partnership Project’s (3GPP) 3rd Generation (3G) Universal Mobile Telecommunications System (UMTS) and 4th Generation (4G) Long-term Evolution (LTE), LTE Advanced, and the Institute of Electrical and Electronics Engineers’ (IEEE) 802.16 standard, also known as WiMax. The use of wireless technologies with “machine-to-machine” communications creates new opportunities for the deployment of M2M modules in locations without fixed-wire Internet access, but also creates a significant new class of problems that need to be solved. First, many wireless wide-area networking standards were designed and optimized for mobile phones, which may be continuously connected to the network during the day (i.e. non-sleeping hours for most subscribers while they may charge phones at night), in order to receive inbound phone calls and messages. In this case, the radio may be in an idle state but utilizing discontinuous reception, but the radio is still active and drawing power in order to receive and process incoming signaling from the network such as a Public Land Mobile Network (PLMN). A need exists in the art to make wireless M2M communications efficient in order to conserve battery life and radio-frequency spectrum resources.

Since the packets transmitted and received by a wireless module will likely traverse the public Internet for many applications, a need exists in the art to (i) prevent eavesdropping at intermediate points along the path of packets transmitted and received, (ii) allow endpoints to verify the identity of the source of packets received. A need exists in the art for a wireless module and a monitoring server to leverage established public key infrastructure (PKI) techniques and algorithms. A need exists in the art for communication to be secured without requiring the established, but relatively processing, bandwidth, and energy intensive security protocols, such as IPSec, Transport Layer Security (TLS), and Secure Socket Layer (SSL). The establishment of these links requires extra overhead in the form of packet handshakes and/or key exchanges at levels including the network and transport layer of the traditional Open Systems Interconnection (OSI) model. M2M applications frequently require small, periodic messages sent between a wireless module and a monitoring server, where the wireless module sleeps between the messages. M2M applications may lever-

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age wired modules as well which also sleep between messages. During relatively long periods of sleep such as 30 minutes or more, the a wireless or wired network with intermediate firewalls will often tear down the network and/or transport layer connections, which means the wireless module would need to re-negotiate or reestablish the secure tunnels each time the wireless module wakes and seeks to send a relatively small message to a server. A need exists in the art for supporting established security protocols with an external application, without requiring them to be implemented on a module due to the relatively long periods of sleep and other complexities from inactivity in the module.

Next, a need exists in the art for the communication between a module and a monitoring server to be highly energy and bandwidth efficient in order to reduce energy consumption over the operating lifetime of a module. A limiting factor for a wireless module for M2M applications deployed or installed into the field is the lifetime of the battery of the wireless module. If the transmission techniques for the wireless module are not energy efficient, the system will require more frequent manual intervention for the replacement or recharging of batteries. If the battery becomes sufficiently low, then communication with the wireless module will be lost, or the frequency would have to be reduced for sensor measurements sent by the wireless module or actuator commands sent by a monitoring server. The energy saving techniques for transmitting and receiving data should leverage established Internet protocols, in order to utilize the public Internet, in addition to the need for secure communications noted above. For wired modules operating for years or decades, a significant cost will be the power consumed from land-line power.

Further, a need exists in the art for the secure, energy efficient communications that support Internet protocols to support intermediate firewalls that may exist along the path of packets sent and received by both a wireless module and a monitoring server. Without support for communication through an intermediate firewall, packets may be blocked by the firewall and the M2M application would not properly function in this case. A need exists in the art for techniques of secure and energy-efficient communications between modules and monitoring servers to support a wide variety of manufacturers of modules and M2M applications. Currently, there are dozens of manufacturers and form-factors of modules, and this diversity will continue to increase for the foreseeable future. By leveraging standards such as the Internet and PKI technologies, an efficient, secure, and highly scalable system of communicating could support the wide variety of modules.

In addition, the utilization of PKI technologies in modules can increase security, but a number of technical challenges must be addressed. These challenges increase if a deployed module required updated private/public key pairs after operation begins. The typical paradigm of “swapping out a SIM card” (which also depend on a pre-shared secret key Ki embedded in the card) with mobile phones may not be applicable or cost effective with modules, where swapping out the SIM card could be burdensome. A need exists in the art to allow for a deployed module to securely and automatically begin using new private and public keys (i.e. without human intervention such as swapping out a SIM card). Newer PKI technologies may offer a wide variety of algorithms for ciphering with public keys, and a need exists in the art for the utilization of new public and private keys to support the wide variety of algorithms, even after a module has been installed. In other words, a system should

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preferably both be highly secure and also flexible enough to adopt new security keys and standards. A need exists in the art for a scalable and secure method of associating a module identity with a module public key, when the module begins utilizing a new public key. A need exists in the art for a module to efficiently be able to utilize multiple public/private key pairs at the same time, such as with different service providers or different applications simultaneously.

Another desirable feature is for an M2M module to efficiently and securely communicate with applications. Applications can include a web-based interface for users to view status or input settings for a plurality of modules, and the modules may be associated with an M2M service provider. However, a set of PKI algorithms, keys, and communication protocols within used by the module for efficient communications module may not be directly compatible with an application. As one example, the application on a web server may prefer to use a transport layer security (TLS) protocol with transmission control protocol (TCP) datagrams, while for energy efficiency and to conserve battery life, an M2M module may prefer to use user datagram protocol (UDP). A need exists in the art for an intermediate server to securely translate secure communications to/from a module into secure communication from/to an application. As another example, it would be desirable for a module to support elliptic key cryptography (ECC), while the application may support RSA-based cryptography, and therefore a need exists in the art for a server to securely translate between the two cryptographic methods, thereby allowing the M2M module to communicate with the application.

And other needs exist in the art as well, as the list recited above is not meant to be exhaustive but rather illustrative.

SUMMARY

Methods and systems are provided for secure and efficient communication using a server to communicate with modules and an application. The modules and application can support “Machine to Machine” communications. The methods and systems contemplated herein can also support other applications as well, including mobile phone handsets connecting to a wireless network. An objective of the invention is to address the challenges noted above for securing the deployment of modules that utilize PKI algorithms and keys, as well as increasing efficiency in order to reduce power consumption, including extending the battery life of a module, if present. More efficient communication can also conserve valuable radio-frequency spectrum, among other benefits. Using a server for secure and reliable communication of data between an application and a module can increase the value and usefulness of modules for a user.

An exemplary embodiment may take the form of methods and systems for a server to securely receive data from a module and forward the data to an application server, and an application may operate on the application server. The application can include a graphical user interface for a user to visually see reports and/or control modules. The module, server, and application can preferably include a set of cryptographic algorithms for use in sending and receiving data. The cryptographic algorithms can include asymmetric ciphering algorithms, symmetric ciphering algorithms, secure hash algorithms, digital signature algorithms, key pair generation algorithms, a key derivation function, and/or a random number generator.

The module can utilize the set of cryptographic algorithms to securely generate or derive a module private key

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and a module public key. The module private key and module public key can be generated either (i) upon initial use or installation of the module, or (ii) at a subsequent time after initial use such as when a new set of key pairs are required or are useful for continued operation of the module. After deriving the module public key and module private key, the module private key is preferably recorded in a secure or protected location in a nonvolatile memory within the module. The module may then utilize the recorded pre-shared secret key to authenticate with a server that also records or has access to the pre-shared secret key. The authentication could comprise either using message digest with the pre-shared secret key, or using the pre-shared secret key as a symmetric ciphering key, and the authentication may also utilize a second key derived by both the module and the server using the pre-shared secret key. After authentication, the server can authoritatively record the derived module public key with the module identity in a database. Thus, the use of a pre-shared secret key can ensure the submitted module public key is validly associated with the module and module identity. The module can be associated with a monitored unit and the module can use a sensor to collect data regarding the monitored unit. The module may also optionally include an actuator for controlling a state of the monitored unit, although the actuator may optionally be omitted.

The server can include a private key associated with the server and the derived public key associated with the module. The server public key can leverage established public key infrastructure (PKI) standards, such as X.509 v3 certificates and RSA or elliptic curve cryptography (ECC) algorithms and include a digital signature from a certificate authority. The server can use a module controller and an operating system plus a connection to the Internet to monitor a socket for incoming messages from a module. After receiving the module public key, including potentially after a period of sleep or dormancy by the module, the server can receive a message, where the message includes a module identity and a module encrypted data. The module encrypted data can include a server instruction, a security token, and additional data such as a sensor measurement. The server can decrypt the module encrypted data using the received module public key and extract plaintext data from the module encrypted data.

The server can establish a secure connection with the application server using a secure connection setup, which could comprise the initial handshake messages for a transport-layer security protocol such as transport layer security (TLS) or IPsec. The secure connection setup can include the transfer of a server public key and an application server public key. The server can send an application message to the application server using a secure connection data transfer, where the application message includes data received from the module such as a sensor measurement or sensor data. The server can use (i) an RSA-based asymmetric ciphering algorithm and first public key with the application server to securely transfer a first symmetric key to the application server, and (ii) an ECC-based asymmetric ciphering algorithm and second public key with the module to securely transfer a second symmetric key to the module. The server may also preferably use a transmission control protocol (TCP) with the application server and a user datagram protocol (UDP) with the module. The application message to the application server can include a server identity, an encrypted update instruction, and the sensor data. The sensor data may also include a sensor identity. The server can use a first Internet protocol address and port

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(IP:port) number for receiving the message from the module and a second IP:port number for sending the application message to the application server. The application server can record the sensor data in an application database for subsequent processing and analysis for a user or other business or commercial needs.

In another embodiment, the module may be deployed within a wireless network such as a 4G LTE network or a WiFi network. The module can change state between a sleep state and an active state, wherein the sleep state may utilize a few milliwatts or less and the active state, including transmission of radio signals, may utilize several hundred milliwatts of power or more. After being installed next to a monitored unit, the wireless module can wake from a sleep or dormant state, utilize a sensor to collect data associated with the monitored unit, connect to the wireless network and the Internet, and send the sensor data to a server. During an active period, the module can use a UDP IP:port number to both send a message to the server and receive a response to the server. The message as a UDP datagram can be a UDP Lite datagram and with a checksum only applied to the packet header. A UDP Lite datagram with sensor data can include channel coding for the body of the datagram to mitigate the effect of bit errors. Or, a regular UDP packet could be sent in multiple copies in order to provide forward error correction.

In another embodiment of the present invention, the application server may send an application message to the server using a secure connection data transfer. The application message could be encrypted using a first server public key and could include a module identity and a module instruction. The module instruction can include an actuator setting, and also optionally an actuator identity (since the module may include multiple actuators). The server can decrypt encrypted data within the application message and record the module identity and module instruction in memory or a module database. Since the module can transition between periods of sleep and active states to conserve power, after receiving the application message the server can wait until a next message is received from the module with the module identity before sending the module instruction in a response. After waiting for the next message, the server can send the module instruction to the module in a server encrypted data using a second server public key. The first and second server public keys can use different cryptographic algorithms that are not directly compatible (i.e. the first server public key could be RSA-based and the second server public key could be ECC-based).

In another embodiment, the server can securely send the module a set of parameters, where the set of parameters includes values to define an equation for an elliptic curve. The values could comprise constants and variables such that the module can calculate a new elliptic curve, and the elliptic curve can be different than standard, published curves. The set of parameters could be sent from the server to the module in a server encrypted data, where the server encrypted data was processed using any of (i) a first module public key, (ii) a symmetric key, and (iii) a shared secret key. The module can use the set of parameters, a random number generator, and a key generation function within a cryptographic algorithms in order to generate a new key pair, which could comprise a second module public key and a second module private key. The module can securely and/or authoritatively send the second module public key to the server, where the security includes the use of the first module public key and/or the shared secret key.

Continuing with this embodiment, after the server confirms the proper receipt of the second module public key in a response message, the server and the module can begin secure communications between them using the second module public key. By using this exemplary embodiment, security can be further increased with the server and module using an elliptic curve that can be unique, non-standard, or defined between them and security therefore increased. In this exemplary embodiment, the parameters to define the elliptic curve equation are sent securely to the module, so an observer along the flow of data could not observe the elliptic equation being used with a public key.

In yet another embodiment, the server can receive a first message with a module identity and a module encrypted data, where the first module encrypted data includes a first sensor measurement. The server can use a first module public key associated with a first module public key identity to decrypt the first module encrypted data. As one example, (a) the first module encrypted data could be ciphered with a symmetric key, and (b) the symmetric key could have been communicated using the first module public key (including using the first module public key to verify a module digital signature in a session where the symmetric key was transferred), and therefore (c) the module encrypted data could be encrypted using the first module public key. The server can also use a first server public key to decrypt the first module encrypted data, such as the symmetric key being derived using both the first module public key and the first server public key and a key derivation function within a cryptographic algorithms. The server can extract the first sensor measurement and send the data to an application server in an application message. The application message could be encrypted using a second server public key. The first and second server public keys can be different because they could each be associated with a different algorithm or defining equation.

Continuing with this embodiment, the server can send a module instruction and a set of parameters to the module, where the module is instructed to derive a new set of keys, and the module can subsequently derive a second module public key and a second module private key after receiving the module instruction. The module can then send the second module public key, a second module public key identity, and the module identity to the server. The server can receive a second module encrypted data that includes a second sensor data, where the second sensor data is encrypted using the second module public key. As one example, (a) the second module encrypted data could be ciphered with a symmetric key, and (b) the symmetric key could have been communicated using the second module public key (including using the second module public key to verify a module digital signature in a session where the symmetric key was transferred), and therefore (c) the module encrypted data could be encrypted using the second module public key. The server can extract the second sensor data using the second module public key. The server can use the second server public key to send a second application message with the second sensor data to the application server. Note that the module public key can change, but both (i) the second server public key used with the application server and also (ii) keys associated with the application server did not change. In this manner according to this embodiment, a module can derive a new public and private key while a server and application server can continue to communicate using existing public and private keys.

In another embodiment, the application server can use a module public key and an asymmetric ciphering algorithm

to encrypt a module instruction. The application server can also include a digital signature of the module instruction using the application server private key. The encrypted module instruction and digital signature can be sent to a server in an application message, and the application message can also include an identity of the application server. The server can wait until a message is received from a module, and then send the encrypted module instruction and digital signature to the module in a response. The module can read receive the response, read the identity of the application server, select a public key of the application server, verify the digital signature of the module instruction, and decrypt the module instruction using the module private key. The module can then apply the module instruction and send a message with a confirmation. In this manner, the module may receive instructions from the application that are not decrypted by the server.

These as well as other aspects and advantages will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Various exemplary embodiments are described herein with reference to the following drawings, wherein like numerals denote like entities.

FIG. 1a is a graphical illustration of an exemplary system, where a server and a module connect to the Internet, in accordance with exemplary embodiments;

FIG. 1b is a graphical illustration of hardware, firmware, and software components for a module, in accordance with exemplary embodiments;

FIG. 1c is a graphical illustration of hardware, firmware, and software components for a server, in accordance with exemplary embodiments;

FIG. 1d is a graphical illustration of hardware, firmware, and software components for an application server, in accordance with exemplary embodiments;

FIG. 1e is a graphical illustration of the components within a module, in accordance with exemplary embodiments;

FIG. 1f is a graphical illustration of the components within a server, in accordance with exemplary embodiments;

FIG. 1g is a graphical illustration of the components in a set of cryptographic algorithms, in accordance with exemplary embodiments;

FIG. 1h is an illustration of a certificate that includes a PKI public key, where the key comprises an elliptic curve cryptography (ECC) key, in accordance with exemplary embodiments;

FIG. 1i is a graphical illustration of an exemplary system that includes a user, an application, a set of servers, and a set of modules, in accordance with exemplary embodiments;

FIG. 2 is a graphical illustration of an exemplary system, where a module sends a message to a server, and where the server responds to the message, in accordance with exemplary embodiments;

FIG. 3 is a flow chart illustrating exemplary steps for a server to receive a message from a module, in accordance with exemplary embodiments;

FIG. 4 is a flow chart illustrating exemplary steps for a server to process a message, including verifying a module's identity and decrypting data, in accordance with exemplary embodiments;

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FIG. 5a is a flow chart illustrating exemplary steps for a server to process a response for a module, including sending and signing an module instruction, in accordance with exemplary embodiments;

FIG. 5b is a flow chart illustrating exemplary steps for a server to communicate with a module that has derived a public key and private key, in accordance with exemplary embodiments;

FIG. 6a is a simplified message flow diagram illustrating an exemplary message received by a server, and an exemplary response sent from the server, in accordance with exemplary embodiments;

FIG. 6b is a simplified message flow diagram illustrating an exemplary message received by a server, wherein the message includes a derived module public key, in accordance with exemplary embodiments;

FIG. 7 is a simplified message flow diagram illustrating an exemplary system with exemplary data transferred between a module and an application using a server, in accordance with exemplary embodiments;

FIG. 8 is a simplified message flow diagram illustrating an exemplary system with exemplary data transferred between a module and an application using a server, in accordance with exemplary embodiments;

FIG. 9 is a simplified message flow diagram illustrating exemplary data transferred between (i) a server and an application and between (ii) a server and a module, in accordance with exemplary embodiments;

FIG. 10 is a flow chart illustrating exemplary steps for a server to receive a module instruction within an application message, and for the server to send the module instruction to a module, in accordance with exemplary embodiments;

FIG. 11 is a flow chart illustrating exemplary steps for a server to communicate with an application and a module, in accordance with exemplary embodiments.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF THE INVENTION

FIG. 1a

FIG. 1a is a graphical illustration of an exemplary system, where a server and a module connect to the Internet, in accordance with exemplary embodiments. The system 100 includes a module 101 operating within a wireless network 102. System 100 can also include a module provider 109, an Internet 107, and an M2M service provider 108, a certificate authority 118, and a monitored unit 119. M2M service provider 108 can include a server 105. System 100 is illustrated without specific packet transmissions between module 101 and M2M service provider 108. Examples of the communications and messages pertaining to the present invention will be illustrated in later Figures. As contemplated herein, machine-to-machine communications may comprise communication between a module 101 and a server 105, such that data can be transferred between the two with minimal manual intervention, although manual intervention can be required to set up system 100 and any occasional manual maintenance required. As contemplated herein, machine-to-machine communications may also be referred to as “the Internet of things” (IoT). Also note that module 101 may comprise a wireless module, such that module 101 can communicate with wireless network 102 using a radio and an antenna. Thus, either a wireless or a wired configuration for module 101 can be utilized in the present invention.

If module 101 operates as a wireless module, module 101 and wireless network 102 can communicate using a base

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station 103. Module 101 and wireless network 102 can utilize a variety of wireless technologies to communicate, including WiFi, WiMax, a 2nd generation wireless wide area network (WAN) technology such as General Packet Radio Services (GPRS) or Enhanced Data rates for GSM Evolution (EDGE), 3rd Generation Partnership Project (3GPP) technology such as 3G, 4G LTE, or 4G LTE Advanced, and other examples exist as well. A wired module 101 can connect to the Internet 107 via a wired connection such as an Ethernet, a fiber optic, or a Universal Serial Bus (USB) connection (not shown).

Generally, the communication techniques described herein can be independent of the network technologies utilized at the physical and data-link layers, so long as the underlying network provides access to the Internet 107 and supports Internet Protocols (IP). The Internet 107 can be an IPv4 or an IPv6 packet-switched based network that utilizes standards derived from the Internet Engineering Task Force, such as RFC 786 (User Datagram Protocol), RFC 793 (Transmission Control Protocol), and related protocols. The Internet 107 can be the public Internet comprising globally routable IP addresses, or a private network that utilizes private IP addresses. Although Internet 107 is illustrated as the globally routable public Internet in FIG. 1, Internet 107 could also be a private Internet that is (i) not globally routable and (ii) only accessible to authorized modules and servers. As one example of a private Internet 107, Internet 107 could use private IP addresses for nodes on the network, and in this case Internet 107 could be referred to as an intranet or private network. Alternatively, Internet 107 could be a private network layered on top of the publicly routable Internet via secured and encrypted connections. The specific numbers for IP addresses and port numbers shown in FIG. 1 and other figures are illustrative and any valid IP address or port number can be used, including an IPv4 and an IPv6 address.

When operating in a wireless network configuration, module 101 can access the Internet 107 via the wireless network 102. In the wireless network configuration, module 101 can be a wireless handset, a cellular phone, a smart-phone, a tablet computer, a laptop, a computer with a radio, a tracking device, or a circuit board with a radio that accesses wireless network 102. Examples of wireless modules that utilize a wireless WAN such as 2G and 3G networking technologies include the Motorola® G24-1 and Huawei® MC323. Example manufacturers of wireless modules in 2012 include Sierra Wireless® and Telit®. In a wired configuration (not shown), module 101 can be a computer, security camera, security monitoring device, networked controller, etc. A more detailed depiction of exemplary components of a module 101 is included in FIG. 1b and FIG. 1e below. Module 101 could also comprise a “point of presence” payment terminal, such that a sensor associated with module 101 could collect payment information such as an account number from a credit card or similar payment card. Module 101 could communicate with the payment card via a magnetic reader or near-field wireless communications, and in this case the magnetic reader or antenna for near-field communications can function as a sensor. Module 101 could also operate as a “smartcard” such that an end user presents module 101 to merchants for payments.

Wireless network 102 may comprise either a wireless local area network (LAN) such as an 802.11 WLAN, Bluetooth, or Zigbee among other possibilities, and module 101 operating in wireless mode could communicate with a base station 103 of a wireless network 102 using a radio and an antenna. Wireless network 102 could operate as a Mode II

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device according to FCC Memorandum Opinion and Order (FC-12-36) and related white space regulation documents. If module **101** supports IEEE 802.15.4, then wireless network **102** could be a Zigbee network, an ISA100.11a standards-based network, or a 6LoWPAN network as described by IETF RFC 4944. Other possibilities exist as well for the wireless technology utilized by a wireless network **102** and module **101**, operating in a wireless mode, without departing from the scope of the present invention.

Module **101** can collect data regarding a monitored unit **119** and periodically report status to an M2M service provider **108** or a server **105**. Examples of a monitored unit **119** can include a vending machine, an alarm system, an automobile or truck, a standard 40-foot or 20-foot shipping container, or industrial equipment such as a transformer on an electrical grid or elevator in a building. Additional examples of a monitored unit **119** include can also include a pallet for shipping or receiving goods, an individual box of pharmaceuticals, a health monitoring device attached to a person such as a pacemaker or glucose monitor, and a gate or door for opening and closing. Other examples exist as well without departing from the scope of the present invention. Module **101** can utilize a sensor to measure and collect data regarding a parameter of monitored unit **119** such as temperature, physical location potentially including geographical coordinates from a Global Positioning System (GPS) receiver, radiation, humidity, surrounding light levels, surrounding RF signals, weight, vibration and/or shock, voltage, current, and/or similar measurements. If monitored unit **119** is a person or a health monitoring device associated with a person, then relevant health data could be recorded by module **101** in order to transmit to a M2M service provider **108**, which could be associated with a health service such as a hospital, doctor's office, or a similar health service. Module **101** could also periodically record a picture, image, or video of or around monitored unit **119**, using either visible or infrared light.

As illustrated in FIG. 1a, wireless network **102** may include a wireless network firewall **104** and M2M service provider **108** may include a server network firewall **124**. These firewalls may be used to secure communication at the data link, network, transport, and/or application layers of communications using the Internet **107**. Firewalls **104** and **124** could perform network address translation (NAT) routing or operate as symmetric firewalls, and selectively filter packets received through Internet **107** in order to secure system **100**. The firewall functionality of firewalls **104** and **124** could be of many possible types, including a symmetric firewall, a network-layer firewall that filters inbound packets according to pre-determined rules, an application-layer firewall, or a NAT router, as examples. Although a single firewall **104** and **124** is illustrated in wireless network **102** and with M2M service provider **108**, respectively, firewall **104** and **124** may each comprise multiple firewalls that operate in conjunction and the combined operation may be considered a single firewall **104** and **124**, respectively. Firewall **104** and/or firewall **124** can include a firewall port binding timeout value **117** (illustrated in FIG. 2), which can represent the time allowed for an inbound packet from the Internet **107** to pass through firewall **104** or firewall **124** after module **101** or server **105**, respectively, sends a packet out. Firewall port binding timeout value **117** may be determined on a per-protocol basis, such as an exemplary time of 60 seconds for UDP packets and 8 minutes for TCP packets, although other time values for a firewall port binding timeout value **117** are possible as well. Inbound packets from Internet **107** to module **101** may be dropped by firewall

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104 after a time exceeding firewall port binding timeout value **117** has transpired since the last packet transmitted by module **101**.

According to a preferred exemplary embodiment, module **101** may preferably record a module private key **112**. As described in additional figures below, module **112** can generate a key pair comprising a module private key **112** and a module public key **111**, where module private key **112** resides within module **101** and may not be shared or transmitted to other parties. Alternatively, the present invention also contemplates that module **101** does not derive its own module private key **112**, and rather module private key **112** is securely loaded or transmitted to module **101**. Module **101** may also be associated with a module provider **109**. Module provider **109** could be a manufacturer or distributor of module **101**, or may also be the company that installs and services module **101** or associates module **101** with monitored unit **119**. Although not illustrated in FIG. 1a, module provider **109** could deliver module **101** to an end-user, where the end-user associates module **101** with monitored unit **119**. Module provider **109** can record a module public key **111** and a certificate **122** (illustrated below in FIG. 1e and FIG. 1h) for module **101**. Module public key **111** may be associated with a module public key identity **111a**, which could be an identifier of module public key **111**. Module **101** may utilize a plurality of module private keys **112** and module public keys **111** during the operation of a system **100**, although the use of a plurality of keys may not be required in order to use some embodiments of the invention contemplated herein.

As discussed below, a module **101** may utilize multiple module public keys **111** over the lifetime of module **101** (including multiple corresponding module private keys **112**), and module public key identity **111a** can be used to select and/or identify the correct module public key **111**. Module public key identity **111a** could be a string or sequence number uniquely associated with module public key **111**. As illustrated in FIG. 1a, module public key identity **111a** may preferably not be included in the string or number comprising module public key **111**, but rather associated with the string or number comprising module public key **111**, and in this case the two together (module public key identity **111a** and the string or number for module public key **111**) may be used to refer to module public key **111** as contemplated herein.

The module public key **111** can optionally be signed by a certificate authority **118** in order to confirm the identity of module **101** and/or the identity of module provider **109**. Alternatively, module provider **109** may have its own provider public key **120** and provider private key **121**. Module provider **109** may have its provider public key **120** signed by a certificate authority **118** and recorded in a certificate **122** (with an exemplary certificate **122** illustrated in FIG. 1h below), and then module provider **109** could sign module public key **111**. In this manner, module provider **109** can also function as a certificate authority **118** for module **101**. Thus, the validity of module public key **111** could be checked with module provider **109**, and the wireless module provider's **109** provider public key **120** could be checked against certificate authority **118**. Other configurations for signing public keys and using certificates with public keys are possible as well without departing from the scope of the present invention.

Public keys and private keys as contemplated in the present invention, including module public key **111** and module private key **112** and additional keys described herein, may leverage established standards for Public Key

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Infrastructure (PKI). Public keys may be formatted according to the X.509 series of standards, such as X.509 v3 certificates, and subsequent or future versions, and these keys may be considered cryptographic keys. The keys can support standards such as the International Organization for Standardization (ISO) ISO/IEC 9594 series of standards (herein incorporated by reference) and the Internet Engineering Task Force (IETF) RFC 5280 titled "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile" (herein incorporated by reference), including future updates to these standards.

Module public key **111** and module private key **112**, as well as the other private and public keys described within the present invention, could be generated using standard software tools such as Openssl, and other tools to generate public and private keys exist as well. Public and private keys as contemplated herein could be recorded in a file such as a *.pem file (Privacy-enhanced Electronic Mail), a file formatted according to Basic Encoding Rules (BER), Canonical Encoding Rules (CER), or Distinguished Encoding Rules (DER), or as text or binary file. Other formats for public and private keys may also be utilized as well, including proprietary formats, without departing from the scope of the present invention. As contemplated herein, a key may also comprise either a public key or a private key. A public key as contemplated herein may also be considered a certificate or a public certificate. A private key as contemplated herein may also be considered a security key or a secret key.

Other configurations besides the one illustrated in FIG. 1a are possible as well. Server **105** could reside within wireless network **102** in a data center managed by wireless network **102**. Wireless network **102** could also operate as a module provider **109**. Although a single module **101** and server **105** are illustrated in FIG. 1a, system **100** could comprise a plurality of each of these elements. Module **101** could also record sensor data pertaining to a plurality of monitored units **119**. Module **101** could be mobile, such as physically attached to a truck or a pallet, and module **101** could connect to a series of different wireless networks **102** or base stations **103** as module **101** moves geographically. Other configurations are possible as well without departing from the scope of the present invention.

FIG. 1b

FIG. 1b is a graphical illustration of hardware, firmware, and software components for a module, in accordance with exemplary embodiments. FIG. 1b is illustrated to include many components that can be common within a module **101**, and module **101** may also operate in a wireless configuration in order to connect with a wireless network **102**. Module **101** may consist of multiple components in order to collect sensor data or control an actuator associated with a monitored unit **119**. In a wireless configuration, the physical interface **101a** of module **101** may support radio-frequency (RF) communications with networks including a wireless network **102** via standards such as GSM, UMTS, mobile WiMax, CDMA, LTE, LTE Advanced, and/or other mobile-network technologies. In a wireless configuration, the physical interface **101a** may also provide connectivity to local networks such as 802.11 WLAN, Bluetooth, or Zigbee among other possibilities. In a wireless configuration, module **101** could use a physical interface **101a** be connected with both a wireless WAN and wireless LAN simultaneously. In a wired configuration, the physical interface **101a** can provide connectivity to a wired network such as through an Ethernet connection or USB connection.

The physical interface **101a** can include associated hardware to provide the connections such as radio-frequency

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(RF) chipsets, a power amplifier, an antenna, cable connectors, etc., and additional exemplary details regarding these components are described below in FIG. 1e. Device driver **101g** can communicate with the physical interfaces **101a**, providing hardware access to higher-level functions on module **101**. Device drivers **101g** may also be embedded into hardware or combined with the physical interfaces. Module **101** may preferably include an operating system **101h** to manage device drivers **101g** and hardware resources within module **101**. The operating systems described herein can also manage other resources such as memory and may support multiple software programs operating on module **101** or server **105**, respectively, at the same time. The operating system **101h** can include Internet protocol stacks such as a User Datagram Protocol (UDP) stack, Transmission Control Protocol (TCP) stack, a domain name system (DNS) stack, etc., and the operating system **101h** may include timers and schedulers for managing the access of software to hardware resources. The operating system shown of **101h** can be appropriate for a low-power device with limited memory and CPU resources (compared to a server **105**). An example operating system **101h** for module **101** includes Linux, Android® from Google®, Windows® Mobile, or Open AT® from Sierra Wireless®. Additional example operating systems **101h** for module **101** include eCos, uC/OS, LiteOs, and Contiki, and other possibilities exist as well without departing from the scope of the present invention.

A module program **101i** may be an application programmed in a language such as C, C++, Java, and/or Python, and could provide functionality to support M2M applications such as remote monitoring of sensors and remote activation of actuators. Module program **101i** could also be a software routine, subroutine, linked library, or software module, according to one preferred embodiment. As contemplated herein, a module program **101i** may be an application operating within a smartphone, such as an iPhone® or Android®-based smartphone, and in this case module **101** could comprise the smartphone. The application functioning as a module program **101i** could be downloaded from an "app store" associated with the smartphone. Module program **101i** can include data reporting steps **101x**, which can provide the functionality or CPU **101b** instructions for collecting sensor data, sending messages to server **105**, and receiving responses from server **105**, as described in the present invention.

Many of the logical steps for operation of module **101** can be performed in software and hardware by various combinations of sensor **101f**, actuator **101y**, physical interface **101a**, device driver **101g**, operating system **101h**, module program **101i**, and data reporting steps **101x**. When module **101** is described herein as performing various actions such as acquiring an IP address, connecting to the wireless network, monitoring a port, transmitting a packet, sending a message, receiving a response, or encrypting or signing data, specifying herein that module **101** performs an action can refer to software, hardware, and/or firmware operating within module **101** illustrated in FIG. 1b performing the action. Note that module **101** may also optionally include user interface **101j** which may include one or more devices for receiving inputs and/or one or more devices for conveying outputs. User interfaces are known in the art and generally are simple for modules such as a few LED lights or LCD display, and thus user interfaces are not described in detail here. User interface **101j** could comprise a touch screen if module **101** operates as a smartphone or mobile phone. As illustrated in FIG. 1b, module **101** can optionally

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omit a user interface **101j**, since no user input may be required for many M2M applications, although a user interface **101j** could be included with module **101**.

Module **101** may be a computing device that includes computer components for the purposes of collecting data from a sensor **101f** or triggering an action by an actuator **101y**. Module **101** may include a central processing unit (CPU) **101b**, a random access memory (RAM) **101e**, and a system bus **101d** that couples various system components including the random access memory **101e** to the processing unit **101b**. The system bus **101d** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures including a data bus. Note that the computer components illustrated for the module **101** in FIG. **1b** may be selected in order to minimize power consumption and thereby maximize battery life, if module **101** includes a battery and is not attached to external power. In addition, the computer components illustrated for the module **101** in FIG. **1b** may also be selected in order to optimize the system for both long periods of sleep relative to active communications and also may be optimized for predominantly uplink (i.e. device to network) communications with small packets or messages. The computer components illustrated for the module **101** in FIG. **1b** may also be general-purpose computing components, and specialized components are not required in order to utilize many of the embodiments contemplated herein.

Module **101** may include a read-only memory (ROM) **101c** which can contain a boot loader program. Although ROM **101c** is illustrated as “read-only memory”, ROM **101c** could comprise long-term memory storage chipsets or physical units that are designed for writing once and reading many times. As contemplated within the present invention, a read-only address could comprise a ROM **101c** memory address or another hardware address for read-only operations accessible via bus **101d**. Changing data recorded in a ROM **101c** can require a technician have physical access to module **101**, such as removing a cover or part of an enclosure, where the technician can subsequently connect equipment to a circuit board in module **101**, including replacing ROM **101c**. ROM **101c** could also comprise a nonvolatile memory, such that data is stored within ROM **101c** even if no electrical power is provided to ROM **101c**. Although not illustrated in FIG. **1b**, but illustrated in FIG. **1e** below, module **101** could also include a flash memory **101w**. A primary difference between flash memory **101w** and RAM **101e** may be that reading and writing operations to flash memory **101w** can be slower whereas reading and writing operations to RAM **101e** may be faster, and faster reading and writing operations to memory may be required for processing sensor **101f** signals and securely communicating with a server **105**. For example, module program **101i**, data reporting steps **101x**, operating system **101h**, or device driver **101g** could be stored in flash memory **101w** within module **101** when the module is powered off. These components and/or instructions could be moved from a flash memory **101w** (not shown in FIG. **1b** but shown in FIG. **1e**) into RAM **101e** when the module is powered on. In addition, portions of a RAM **101e** can function as flash memory **101w**, such that module program **101i**, power control steps **101x**, operating system **101h**, or device driver **101g** remain resident in random access memory even when the mobile module **101** is powered off, or powered off for the first time after module **101** is installed or becomes active in wireless

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network **102**. Note that ROM **101c** could be optionally omitted or included in a memory unit within CPU **101b** (not shown).

Although the exemplary environment described herein employs ROM **101c** and RAM **101e**, it should be appreciated by those skilled in the art that other types of computer readable media which can store data that is accessible by a module **101**, such as memory cards, subscriber identity module (SIM) cards, local miniaturized hard disks, and the like, may also be used in the exemplary operating environment without departing from the scope of the invention. The memory and associated hardware illustrated in FIG. **1b** provide nonvolatile storage of computer-executable instructions, data structures, program modules, module program **101i**, and other data for computer or module **101**. Note the module **101** may include a physical data connection at the physical interface **101a** such as a miniaturized universal serial bus adapter, firewire, optical, or other another port and the computer executable instructions such as module program **101i**, data reporting steps **101x**, operating system **101h**, or device driver **101g** can be initially loaded into memory such as ROM **101c** or RAM **101e** through the physical interface **101a** before module **101** is given to an end user, shipped by a manufacturer to a distribution channel, or installed by a technician. In addition, the computer executable instructions such as module program **101i**, data reporting steps **101x**, operating system **101h**, or device driver **101g** could be transferred wirelessly to module **101**. In either case (wired or wireless transfer of computer executable instructions), the computer executable instructions such as module program **101i**, data reporting steps **101x**, operating system **101h**, or device driver **101g** could be stored remotely on a disk drive, solid state drive, or optical disk (external drives not shown).

A number of program modules may be stored in RAM **101e**, ROM **101c**, or possibly within CPU **101b**, including an operating system **101h**, device driver **101g**, an http client (not shown), a DNS client, and related software. Program modules include routines, sub-routines, programs, objects, components, data structures, etc., which perform particular tasks or implement particular abstract data types. Aspects of the present invention may be implemented in the form of a module program **101i** and/or data reporting steps **101x** which are executed by the module **101** in order to provide remote monitoring using a sensor **101f** and/or remote control using an actuator **101y**. In addition, the module program **101i** and/or data reporting steps **101x** can include routines, sub-routines, and similar components to support secure and bandwidth and radio-frequency (RF) efficient communication with a server **105** utilizing the techniques described in the present invention. Further, the module program **101i** and/or data reporting steps **101x** can perform the various actions described in the present invention for the module **101** through instructions the module program **101i** and/or data reporting steps **101x** provide to the CPU **101b**.

A user may enter commands and information into module **101** through an optional user interface **101j**, such as a keypad, keyboard (possibly miniaturized for a mobile phone form-factor), and a pointing device. Pointing devices may include a trackball, an electronic pen, or a touch screen. A user interface **101j** illustrated in FIG. **1b** can also comprise the description of a user interface **101j** within U.S. patent application Ser. No. 14/039,401, filed Sep. 27, 2013 in the name of John Nix, which is herein incorporated in its entirety.

The module **101**, comprising a computer, may operate in a networked environment using logical connections to one

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or more remote computers, such as the server **105** illustrated in FIG. **1a**. Server **105** can also function as a general purpose server to provide files, programs, disk storage, remote memory, and other resources to module **101** usually through a networked connection. Additional details regarding server **105** are provided in FIG. **1c** below. Additional remote computers with which module **101** communicates may include another module **101** or mobile device, an M2M node within a capillary network, a personal computer, other servers, a client, a router, a network PC, a peer device, a base station **103**, or other common network node. The server **105** or a remote computer typically includes many of the elements described above relative to the module **101**, including a CPU, memory, and physical interfaces. It will be appreciated that the network connections shown throughout the present invention are exemplary and other means of establishing a wireless or wired communications link may be used between mobile devices, computers, servers, corresponding nodes, and similar computers.

The module program **101i** and data reporting steps **101x** operating within module **101** illustrated in FIG. **1b** can provide computer executable instructions to hardware such as CPU **101b** through a system bus **101d** in order for a module **101** to (i) collect data from a sensor, (ii) change the state of an actuator **101y**, and (iii) send or receive packets with a server **105**, thus allowing server **105** to remotely monitor or control a monitored unit **119**. The module program **101i** and/or data reporting steps **101x** can enable the module **101** to transmit or send data from sensor **101f** or module **101** by recording data in memory such as RAM **101e**, where the data can include sensor data, a destination IP:port number, a packet or packet header value, an encryption or ciphering algorithm and key, a digital signature algorithm and key, etc. The data recorded in RAM **101e** can be subsequently read by the operating system **101h** or the device driver **101g**. The operating system **101h** or the device driver **101g** can write the data to a physical interface **101a** using a system bus **101d** in order to use a physical interface **101a** to send data to a server **105** using the Internet **107**. Alternatively, the module program **101i** and/or data reporting steps **101x** can write the data directly to the physical interface **101a** using the system bus **101d**.

The module program **101i** and/or data reporting steps **101x**, or operating system **101h** can include steps to process the data recorded in memory such as encrypting data, selecting a destination address, or encoding sensor data acquired by (i) a sensor **101f** or (ii) through a physical interface **101a** such as a thermocouple, shock or vibration sensor, light sensor, or global positioning system (GPS) receiver, etc. The module **101** can use the physical interface **101a** such as a radio to transmit or send the data from a sensor to a base station **103**. For those skilled in the art, other steps are possible as well for a module program **101i** or operating system **101h** to collect data from a sensor **101f** and send the data in a packet without departing from the scope of the present invention.

Conversely, in order for module **101** to receive a packet or response from server **105**, the physical interface **101a** can use a radio to receive data from a base station **103**. The received data can include information from a server **105** and may comprise a datagram, a source IP:port number, a packet or header value, an instruction for module **101**, an acknowledgement to a packet that module **101** sent, a digital signature, and/or encrypted data. The operating system **101h** or device driver **101g** can use a system bus **101d** and CPU **101b** to record the received data in memory such as RAM **101e**, and the module program **101i** or operating system **101h** may

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access the memory in order to process the received data and determine the next step for the module **101** after receiving the data. Processing the received data could include deciphering or decrypting received data with a key, verifying a digital signature with a key, reading an instruction from a server **105**, or similar transformations of the received data. The steps within this paragraph may also describe the steps a module program **101i** or data reporting steps **101x** can perform in order to receive a packet. For those skilled in the art, other steps are possible as well for a module program **101i**, data reporting steps **101x**, or module **101** to receive a packet or response from a server **105** without departing from the scope of the present invention.

Moreover, those skilled in the art will appreciate that the present invention may be implemented in other computer system configurations, including hand-held devices, notebooks, portable computers, multiprocessor systems, microprocessor based or programmable consumer electronics, network personal computers, minicomputers, mainframe computers, and the like. The invention may also be practiced in distributed computing environments, where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices. In addition, the terms "mobile node", "mobile station", "mobile device", "M2M module", "M2M device", "networked sensor", or "industrial controller" can be used to refer to module **101** or its functional capabilities of (i) collecting sensor data regarding a monitored unit **119**, (ii) changing state of an actuator **101y** associated with monitored unit **119**, and/or (iii) communicating the data associated with a monitored unit **119** with a wireless network **102**. The function of module **101** and sensor **101f** could be integrated, and in this case module **101** could also be referred to as a "sensor", "intelligent sensor", or "networked sensor". Further, the term "module" or "monitoring device" can be used to refer to the module program **101i** when module program **101i** provides functional capabilities such as reporting data from a sensor **101f** to a server **105** or receiving instructions for an actuator **101y** from a server **105**. The device driver **101g**, operating system **101i**, and/or module program **101i** could optionally be combined into an integrated system for providing the module **101** functionality. Other possibilities exist as well for the configuration or combination of components illustrated in FIG. **1b** without departing from the scope of the present invention.

FIG. 1c

FIG. **1c** is a graphical illustration of hardware, firmware, and software components for a server, in accordance with exemplary embodiments. The illustrated components for the server **105** in FIG. **1c** include a central processing unit (CPU) **105b**, a random access memory (RAM) **105e**, a system bus **105d**, storage **105m**, an operating system **105h**, and a module controller **105x**. These elements can provide functions equivalent to the central processing unit (CPU) **101b**, RAM **101e**, system bus **101d**, flash memory **101w**, and an operating system **101h** described above in FIG. **1b**, respectively. In general, a server **105** can have higher-end components such as a larger CPU **105b** and greater RAM **105e** in order to support communications with a plurality of modules **101**. Server **105** can comprise a general purpose computer such as a rack mounted server within a data center or rack, or could also comprise a desktop computer or laptop. Server **105** could also be a specialized computer, with hardware and software selected for supporting a plurality of modules **101** connecting and communicating simul-

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taneously. Operating system **101h** can comprise an operating system appropriate for a server such as Linux, Solaris®, or Windows® Server. Server **105** can preferably have a wired Ethernet connection with high bandwidth that is persistently connected to the Internet **107** illustrated in FIG. **1a**, while the Internet **107** connection for module **101** may be transient as module **101** changes between sleep and active states. Module controller **105x** can provide the server-side logic for managing communications and controlling module **101** using a module database **105k**. Server program **105i** can provide functionality for communicating with external servers or nodes, such as an application server **171** illustrated in FIG. **1d**.

A module controller **101x** and server program **105i** may be applications programmed in a language such as C, C++, Java, or Python and could provide functionality to support M2M applications such as remote monitoring of sensors and remote activation of actuators. Module controller **105x** and server program **105i** could also be software routines, sub-routines, linked libraries, or software modules, according to preferred embodiments. Many of the logical steps for operation of server **105**, module controller **105x**, and/or server program **105i** can be performed in software and hardware by various combinations of physical interface **105a**, system bus **105d**, device driver **105g**, and operating system **105h**. When server **105** is described herein as performing various actions such as acquiring an IP address, monitoring a port, transmitting or sending a packet, receiving a message, or encrypting or signing a message, specifying herein that server **105** performs an action can refer to software, hardware, and/or firmware operating within server **105** performing the action.

The server **105** may also include a user interface **105j** such as a display (not shown) which could also comprise any type of display devices such as a liquid crystal display (LCD), a plasma display, and an organic light-emitting diode (OLED) display, or a cathode ray tube (CRT). A user interface **105j** for the server **105** may optionally be provided remotely such as (i) via a web browser or a secure terminal such as secure shell (SSH) with (ii) another computer operated by an administrator (not shown). A user or administrator may enter commands and information into server **105** through a user interface **105j**, such as a keypad, keyboard, and a pointing device. Pointing devices may include a trackball, an electronic pen, or a touch screen. In addition, the server **105** may store computer executable instructions such as module controller **105x** or server program **105i** on storage **105m**. Storage **105m** may comprise a disk drive, a solid-state drive, an optical drive, or a disk array. Module controller **101x** can manage communications with module **101** and may be downloaded and installed on the server **105**. As noted previously and elsewhere herein, module program **101i** and module controller **105x** can preferably interoperate with each other in order to collect sensor data and control an actuator associated with a monitored unit **119**.

The server program **105i** and/or module controller **101x** operating within server **105** illustrated in FIG. **1c** can provide computer executable instructions to hardware such as CPU **105b** through a system bus **105d** in order to (i) receive a message from the module **101** and (ii) send a response, wherein the message can include sensor **101f** data and the response can include an acknowledgement of the message and/or an instruction to the module **101**. The module controller **105x** can enable the server **105** to send a response to a message from module **101** by recording data associated with module **101** in memory such as RAM **105e**, where the data can include an instruction from module **101**, a destination IP:port number, a packet or packet header

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value, and the data can be processed using an encryption or ciphering algorithm or key, a digital signature algorithm or key, etc.

The server program **105i** can enable (a) the server **105** to send a datagram, packet, or an application message to an application server **171** by (b) recording data associated (i) a with module **101** or (ii) other M2M service control information in memory such as RAM **105e**, where the data can include information from module **101**, a destination IP:port number, a packet or packet header value, and the information could be processed using an encryption or ciphering algorithm or key, a digital signature algorithm or key, etc. The operating system **105h** or the device driver **105g** can write the data from RAM **105e** to a physical interface **105a** using a system bus **105d** and an Ethernet connection in order to send the data via the Internet **107** illustrated in FIG. **1a**. Alternatively, the software program **105i** and/or module controller **105x** can write the data directly to the physical interface **105a** using the system bus **105d**.

The server **105** can utilize the physical interface **105a** to receive data from a module **101** and/or application **171i** using a local area network such as Ethernet, although the physical interface **105a** of server **105** could also utilize a wireless connection. The server **105** can listen for data from the Internet **107** using port number and/or a TCP/UDP socket. The received data from a module **101** can be a message formatted according to an Internet packet or datagram or series of datagrams inside Ethernet packets and include information from a module **101** such as a source IP address and port number, an identity of the module, sensor data that may be encrypted, and/or a digital signature of the module. The received data from application **171i** can comprise a series of datagrams formatted according to Internet Protocol and/or datagrams inside Ethernet packets. The received data or message from application **171i** can include information regarding application **171i** and/or server **105**, such as a source IP address and port number associated with application **171i** or application server **171**, an identity of the server, actuator instructions or commands for a module **101** that may be encrypted, and a digital signature associated with the application **171i**.

When server **105** receives messages or data, the operating system **105h** or device driver **105g** can record the received data from module **101** or application **171i** via physical interface **105a** into memory such as RAM **105e**. The server program **105i** or operating system **105h** may subsequently access the memory in order to process the data received. The server program **105i** and/or module controller **105x**, or operating system **105h** can include steps to process the data recorded in memory and received from the module **101** or application **171i**, such as parsing the received packet, decrypting data, verifying a digital signature with a key, or decoding sensor data included in a message from the module.

The server **105** and/or server program **105i** may communicate with application **171i** by sending and receiving packets over a LAN or the Internet **107**, using a physical interface **105a** and a wired connection such as Ethernet or possibly a wireless connection as well. The server **105** can use the physical interface **105a** such as an Ethernet connection to send and receive the data from the Internet **107**. For those skilled in the art, other steps are possible as well for a server program **105i** or operating system **105h** within a server **105** to (i) send/receive a packet or message to/from a module **101** and (ii) send/receive a packet or message to/from an application **171i** without departing from the scope of the present invention. Server program **105i** and module controller **105x**

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may optionally be combined within a server 105, or alternatively distributed across different physical computers and function in a coordinated manner using a network.

The device drivers 105g, operating systems 105h, and/or module controller 105x could also optionally be combined into an integrated system for providing the server 105 functionality. Although a single physical interface 105a, device-driver set 105g, operating system 105h, module controller 105x, server program 105i, and user interface 105j are illustrated in FIG. 1c for server 105, server 105 may contain multiple physical interfaces, device drivers, operating systems, software programs, module programs, and/or user interfaces. Server 105 may operate in a distributed environment, such that multiple computers operate in conjunction through a network to provide the functionality of server 105. Also, server 105 may operate in a "virtualized" environment, where server 105 shares physical resources such as a physical CPU 105b with other processes operating on the same computer. And other arrangements could be used as well, without departing from the invention.

FIG. 1d

FIG. 1d is a graphical illustration of hardware, firmware, and software components for an application server, in accordance with exemplary embodiments. Application server 171 can include application 171i. Application 171i can comprise a computer program or collection of computer programs, for managing a plurality of modules 101 using one or more servers 105. Application 171i can include a web portal 171j, service controller 171x, an application database 171k, and cryptographic algorithms 141. During operation, such as when application 171i processes data from/to modules 101 through server 105, application 171i may reside in RAM 171e within an application server 171. Application 171i and the associated computer programs may be recorded in storage 171m so that they may be loaded by operating system 171h upon the startup of application server 171. Web portal 171j can comprise a web server such as Apache and can provide a user interface for a remote user accessing application 171i via an Internet 107. The web portal 171j could include web pages for viewing reports from modules 101 and/or servers 105, and also inputting settings for modules 101 by a user. The web pages could include PHP, active server pages, or Java components, in addition to other elements. Data input and stored by application 171i can be recorded in application database 171k. The data could be inserted or queried using structured query language (SQL) statements. Cryptographic algorithms 141 which may comprise a suite of algorithms or subroutines that can be utilized for (i) deriving a pair of keys comprising a public key and a private key, (ii) encrypting data using public keys, (iii) decrypting data using private keys, (iv) processing secure hash signatures using private keys, and (v) verifying secure hash signatures using public keys, and related software, firmware, or subroutines for implementing a cryptographic system, and cryptographic algorithms 141 are also depicted and described in connection with FIG. 1g below.

Application 171i may be processed by an application server 171 using a CPU 171b. The illustrated components for the application server 171 in FIG. 1d include a central processing unit (CPU) 171b, a random access memory (RAM) 171e, a system bus 171d, storage 171m, an operating system 171h, and an application 171i. These elements can provide functions equivalent to the central processing unit (CPU) 105b, RAM 105e, system bus 105d, storage 105m, and an operating system 105h described above in FIG. 1c, respectively. Application server 171 can comprise a general purpose computer such as a rack mounted server within a

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data center or rack, or could also comprise a desktop computer or laptop. Application server 171 could also be a specialized computer, with hardware and software selected for supporting a plurality of servers 105 or modules 101 connecting and communicating simultaneously. Operating system 171h can comprise an operating system appropriate for a server such as Linux, Solaris®, or Windows® Server. Application server 171 can preferably have a wired Ethernet connection with high bandwidth that is persistently connected to the Internet 107.

An application 171i and/or service controller 171x may be an application programmed in a language such as C, C++, Java, or Python and could provide functionality to support M2M applications such as remote monitoring of sensors and remote activation of actuators. Application 171i can include a service controller 171x. Application 171i and/or service controller 171x could also be a software routine, subroutine, linked library, or software module, according to one preferred embodiment. Application 171i can include a service controller 171x, which can provide the functionality or CPU 171b instructions for the service controller 171x described in the present invention. Service controller 171x can include (i) logic for processing alarms from a module 101 (such as sending out an email or text message to a user), (ii) logic for adjusting actuator 101y settings based upon data from sensor 101f, (iii) accepting user input (possibly via web portal 171j) and then making an associated change in an actuator 101y setting. Service controller 171x can also accept input from external applications (not shown) in order to make decisions regarding module 101, sensor 101f, and/or actuator 101y.

Service controller 171x could be included within an enterprise resource planning (ERP) solution such as SAP® or Oracle® ERP. An external application (not shown) can communicate with the application server 171. As one example, a group of modules 101 could be installed within a manufacturing plant, and when a customer order was entered into the external application such as ERP, the service controller 171x could provide instructions for a group of modules 101 to server 105, such as changing actuators 101y to operate a production line. Other possibilities for service controller 171x exist as well without departing from the scope of the present invention. In general, service controller 171x can manage the overall function of a group of modules 101 through server 105. Service controller 171x may operate at the "user layer" and/or "application layer" of the traditional OSI model.

Many of the logical steps for operation of application server 171 or application 171i can be performed in software by various combinations of physical interface 171a, device driver 171g, operating system 171h, and module controller 105i, where application 171i communicates with module controller 105i over a network. Application 171i and module controller 105i can communicate using an application message 701 (illustrated in FIG. 7 below). When application 171i is described herein as performing various actions such as acquiring an IP address, monitoring a port, transmitting or sending a packet or message, or encrypting or signing a message, receiving a packet or message, specifying herein that application 171i and/or application server 171 performs an action can refer to software, hardware, and/or firmware operating within application server 171 performing the action. Application server 171 or application 171i can send or transmit a message, packet, or data using the steps depicted and described in connection with FIG. 1c for a server 105 to send or transmit a message, packet, or data. Application server 171 or application 171i can receive a

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message, packet, or data using the steps depicted and described in connection with FIG. 1c for a server 105 to receive a message, packet, or data. Application server 171 can utilize hardware components similar to server 105, such as storage 171m can be similar to storage 105m, CPU 171b can be similar to CPU 105b, and physical interface 171a can be similar to physical interface 105a. Application server 171 can use a system bus 171d to connect the hardware components shown within application server 171, and system bus 171d can be similar to system bus 105d depicted and described in connection with FIG. 1c above.

Application server 171 may also comprise a collection of individual computers, where the individual computers could be either centrally located or geographically dispersed, but the individual computers may function in a coordinated manner over a network to operate as an application server 171. In a similar manner, application 171i may be distributed across a plurality of computers, such as in a cloud computing configuration. Application server 171 may be a “virtualized” server, with computing resources shared with other processes operating on a computer.

FIG. 1e

FIG. 1e is a graphical illustration of the components within a module, in accordance with exemplary embodiments. FIG. 1e is illustrated to show a combination of components useful for leveraging the efficient and secure communication techniques described in the present invention. In addition to the components illustrated in FIG. 1b above, module 101 can include a battery 101k, a server public key 114, a wireless module private key 112, a connection to an actuator 101y, a USB interface 101v, a CPU wake controller 101u, a flash memory 101w, a symmetric key 127, a pre-shared secret key 129a, a random number generator 128, cryptographic algorithms 141, a radio 101z, and other components illustrated in FIG. 1e. Not all of the components illustrated in FIG. 1e are required for many exemplary embodiments, and some of the components illustrated in FIG. 1e may also be optionally omitted in exemplary embodiments.

The CPU 101b can comprise a general purpose processor appropriate for the low power consumption requirements of a module 101, and may also function as a microcontroller. In a preferred exemplary embodiment, the CPU 101b is responsible for maintaining a state machine for network and transport layer commands with an external network such as the wireless network 102 illustrated in FIG. 1a, where CPU 101b can manage the overall connection of radio 101z with a wireless network 102. CPU 101b can include additional elements not shown, such as registers, cache memory, an arithmetic logic unit (ALU), which performs arithmetic and logical operations, and a control unit (CU), which extracts instructions from memory and decodes and executes them, calling on the ALU when necessary.

The CPU 101b wake and dormant or sleep states may be controlled by a CPU wake controller 101u to put the module 101 in a dormant state in order to conserve (i) battery life in battery 101k, or (ii) power consumption if land-line power is available, when sensor measurements, actuator control, or radio communications are not needed. The CPU wake controller 101u could optionally be integrated into CPU 101b. The CPU wake controller 101u can also include a timer to periodically wake the CPU 101b in order to perform sensor measurements or communicate with a wireless network 102 or server 105. The flash memory 101w can be a non-volatile memory and may contain a bootloader program 125 and a module program 101i. Bootloader program 125 can comprise a software program or application that is

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initially read by CPU 101b upon power up of module 101 in order to configure interfaces and begin operations including loading module program 101i. Module program 101i is depicted and described in connection with FIG. 1b above. If module 101 operates as a payment card, then CPU wake controller 101u could wake CPU 101b when a radio 101z detects an RF signal from a payment terminal.

Note that CPU wake controller 101u can monitor sensor 101f in order to determine a wake condition for CPU 101b, wherein the CPU 101b remains dormant until sensor 101f reads a state that requires sending a message to a server 105. An example could be sensor 101f comprising a shock and vibration detector or a temperature measuring device such as a thermocouple, and other examples exist as well. The CPU wake controller 101u can leave CPU 101b in a dormant state until a certain threshold of shock and vibration or temperature is recorded by the sensor 101f, and in this manner battery 101k can be conserved so that CPU 101b wakes when a threshold sensor measurement or an alarm condition is reported. The exemplary certain threshold of shock and vibration or temperature recorded by the sensor 101f can also comprise an alarm condition. When CPU 101b is dormant, CPU wake controller 101u can monitor a voltage level output by sensor 101f, and once a threshold voltage level is read by CPU wake controller 101u, CPU wake controller 101u can change CPU 101b from the dormant state to an active state in order to run a module program 101i.

Even without an alarm condition, CPU wake controller 101u can periodically wake CPU 101b to collect sensor data, connect to an external network such as a wireless network 102, and send sensor data to server 105. CPU 101b can include one or more cores of the processor, where each core is an independent actual central processing unit, and the cores can be the units that read and execute program instructions. The instructions can be ordinary CPU instructions such as add, move data, and branch. The dormant state of CPU 101b can comprise a sleep state where a power level used by a core in the processor is less than 0.010 milliwatts during a one second measurement sample, such as when the power supply is essentially removed from the core but power is supplied to memory 101e in order to allow a rapid waking of the CPU 101b or core.

Sensor 101f could be a device to collect environmental data or data regarding a monitored unit 119. Sensor 101f could collect data such as temperature, humidity, pressure, visible light levels, radiation, shock and/or vibration, voltage, current, weight, pH levels, orientation/motion, or the presence of specific chemicals. Sensor 101f could also be a microphone. Sensor 101f could be a magnetic strip reader for credit cards and similar cards, or an antenna for either near-field RF communications, such as reading an RF identity tag. An antenna for a sensor 101f could also collect longer-range RF signals, such as reading long-range radio frequency identity tags. Sensor 101f could also collect biometric data such as heart rate, glucose levels, body temperature, or other health measurements and in this case monitored unit 119 could be a person. The sensor 101f can provide data to the CPU 101b in the form of analog or digital data, which can be communicated via a system bus 101d or physical interface 101a and other electrical interfaces are possible as well. A sensor measurement can comprise the analog or digital data collected by CPU 101b from sensor 101f. A sensor measurement can include processing of the analog or digital data input CPU 101b by sensor 101f, such as averaging over time, using mathematic formulas to convert the raw data from sensor 101f into a usable form.

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Module 101 may also collect sensor data or sensor values using a sensor 101f and CPU 101b, where the data or values are derived from electrical signals output by a sensor 101f. A sensor measurement can comprise the sensor data or sensor values. If module 101 comprises a “point of presence” payment terminal, then a sensor measurement could comprise data read from a payment card.

As contemplated herein, the terms “sensor measurement” and “sensor data” can be used interchangeably, and can also be considered functionally equivalent. Although a single sensor 101f is shown in FIG. 1e, a module 101 could include multiple sensors. Each of the multiple sensors 101f could include a sensor identity 151, which could comprise a number or string to identify the sensor 101f. Or, a sensor identity 151 could also be used with a single sensor 101f. In addition, although sensor 101f is shown as integrated into module 101, sensor 101f could be external to module 101, and connected via an external interface such as through a USB interface 101v or other wired or wireless configuration.

Note that sensor 101f could also connect to module 101 via a WiFi or similar wireless LAN connection such as Zigbee. Radio 101z within module 101 can operate as a WiFi base station (in addition to radio 101z connecting to a wireless network 102), and sensor 101f could contain its own radio and WiFi chipset, such that sensor 101f could send sensor data to module 101 via the WiFi connection (or other wireless LAN connection). In this manner, by utilizing WiFi to connect with sensor 101f, module 101 could connect with a plurality of sensors 101f located in a vicinity of module 101, such as within an exemplary 50 meters. In addition to the WiFi network described, sensor 101f and/or actuator 101y could connect with module 101 via any suitable wireless local area networking technology including, IEEE 802.11, IEEE 802.15.4, an ISA100.11a standards-based network, Bluetooth, and/or a 6LoWPAN.

Actuator 101y could be a device to control a parameter or state for a monitored unit 119, such as changing a voltage or current, activating a switch or relay, turning on or off a microphone or speaker, activating or deactivating a light, and other examples are well known in the art. Actuator 101y could also be a speaker. Actuator 101y could be controlled by module 101 via a digital or analog output from CPU 101b, which could also be transmitted or sent via system bus 101d or a physical interface 101a. Although actuator 101y is illustrated as external to wireless module 101 in FIG. 1e, actuator 101y could also be internal to module 101, and module 101 could include multiple actuators 101y.

Although a single actuator 101y is shown in FIG. 1e, a module 101 could include multiple actuators 101y. Each of the multiple actuators 101y could include an actuator identity 152, which could comprise a number or string to identify the actuator 101y. Or, an actuator identity 152 could also be used with a single actuator 101y. If module 101 comprises a “point of presence” payment terminal, then an actuator 101y could be a printer for printing a receipt. If module 101 comprises a payment card for end users to make payments to merchants, then actuator 101y could be an LED light that turns on upon submission of a payment. Sensors and actuators are well known to those of ordinary skill in the art, and thus are not described in additional detail herein.

Module 101 can include a Universal Serial Bus (USB) interface 101v, which could provide a general and standards-based interface for external connection to a wide variety of sensors 101f, actuators 101y, and external computers such as laptops or mobile phones. Module 101 could also obtain power or recharge a battery 101k through the USB interface 101v. Software programs or instructions to wireless module

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101 could be provided locally through USB interface 101v, including the initial loading of a pre-shared secret key 129a and/or shared secret key 510 described in FIG. 5b below. Module program 101i, operating system 101h, or module private key 112 could be loaded into module 101 via USB interface 101v, another physical interface 101a, or radio 101z. In order to support a preferred small form factor of a module 101, the USB interface 101v could preferably utilize either a micro-USB or mini-USB physical interface, or future similar miniature USB interfaces related to these standard interfaces. Although a USB interface 101v is illustrated in FIG. 1e, alternative interfaces for external communication could be provided, such as a Joint Test Action Group (JTAG) connection, optical, or a proprietary interface such as a “Lightning” connection from Apple, Inc. USB interface 101v and similar hardware interfaces could also be optionally omitted. According to an exemplary embodiment, module 101 uses only a radio 101z to transmit and receive data externally to module 101.

In accordance with an exemplary embodiment, module 101 can comprise a wireless module and include a radio 101z. Note that the use of a radio 101z is not required for module 101, which could also obtain a connection to the Internet 107 via a wired line such as Ethernet. Although not illustrated, radio 101z could include antennas for reception and transmission of RF signals, and even multiple antennas could be used. Although a single radio 101z is illustrated in module 101, module 101 could also contain multiple radios 101z, such that a first radio 101z connects with a WiFi network or functions as a WiFi base station or WiFi client, a second radio 101z connects with a PLMN mobile network such as a wireless network 102, and a third radio 101z connects with a wireless network 102 operating in white-space spectrum, etc. Or, a single radio 101z could be utilized to connect with multiple wireless networks 102 operating in different frequencies with different RF modulation techniques and/or different RF standards.

Radio 101z could also comprise a software defined radio, such that radio 101z could be programmed to change RF protocols and modulation schemes without having to change hardware within a radio 101z. Thus, according to a preferred exemplary embodiment, module 101 can utilize a software defined radio for radio 101z in order allow module 101 to communicate with different wireless networks 102, including new or future standards for a wireless network 102, where the standard was not defined when module 101 was installed. In this manner, module 101 can continue to operate over an extended period such as years by upgrading the software defined radio in a radio 101z as standards used by a wireless network 102 changes, thereby reducing costs for changing a module 101 or a radio 101z within a module in a system 100.

Radio 101z can support wireless LAN standards such as WiFi, Bluetooth, and Zigbee, or similar wireless LAN standards. Radio 101z, if present in a module 101, could also support communication through “white space” spectrum white space spectrum recently approved for use by the Federal Communications Commission (FCC), and in this case radio 101z in module 101 could operate as a Mode I or Mode II device according to FCC Memorandum Opinion and Order (FC-12-36) and related white space regulation documents. Radio 101z illustrated in FIG. 1e can comprise a radio 101z depicted and described in connection with FIG. 1d of U.S. patent application Ser. No. 14/039,401, filed Sep. 27, 2013 in the name of John Nix, the contents of which are herein incorporated in their entirety.

Note that module 101 may also operate as a base station in a wireless LAN, such as an 802.11 base station. When module 101 operates a wireless LAN, radio 101z can function as either a client/node or a base station 103 to support communication from other wireless nodes in physical proximity, such as other nodes within an exemplary 50 meters. The other wireless nodes could comprise a sensor 101f and/or actuator 101y, and in this case a sensor could be referred to as a “networked sensor” and an actuator could be referred to as a “networked actuator”. When radio 101z functions as a base station 103, module 101 can operate as a gateway, providing Internet access to these other nodes or modules 101 within the wireless LAN. Radio 101z can simultaneously function (i) as a base station in a wireless LAN, such as WiFi, and (ii) a client/subscriber on a wireless WAN such as a PLMN. Radio 101z can be selected to support multiple different wireless LAN technologies in addition to WiFi, such as the IEEE 802.15.4 standard or Bluetooth. If radio 101z supports IEEE 802.15.4, then wireless network 102 could be a Zigbee network, an ISA100.11a standards-based network, or a 6LoWPAN network as described by IETF RFC 4944.

In accordance with exemplary embodiments, module 101 can store module private key 112, server public key 114, and module identity 110, and a symmetric key 127 in memory/RAM 101e during operation, such as when CPU 101b is active and the module 101 is connected to a network such as a wireless network 102 during data transmissions. Module private key 112 preferably is recorded in nonvolatile memory such as flash memory 101w, so that module 101 has access to its private key 112 after the private key has been derived or loaded, including times when a battery 101k has been fully drained or removed from module 101 (if module 101 does not utilize a persistent power source such as land-line power). Module private key 112 and module identity 110 could be written into ROM 101c upon manufacture or distribution of module 101, although module 101 can also derive module private key 112 in accordance with exemplary embodiments and store the module private key 112 in a flash memory 101w.

The CPU 101b preferably moves module private key 112 and module identity 110 from nonvolatile memory into volatile memory, including possibly a cache memory within CPU 101b, before sending data through an Internet 107 illustrated in FIG. 1a, in order to speed computations. As a minimum, module private key 112 and module identity 110 will need to be loaded into registers of CPU 101b during computations or use of cryptographic algorithms 141 that require module private key 112 and/or module identity 110, and this move of the data into registers of CPU 101b constitutes a move or copy of module private key 112 and module identity 110 into volatile memory.

Symmetric key 127 can be a secure, shared private key for use with symmetric encryption or symmetric ciphering algorithms 141b (in FIG. 1g below). Symmetric key 127 can be derived by using module public key 111 and/or server public key 114, possibly through the use of a key derivation function 141f (also in FIG. 1g below). Symmetric key 127 can be used for both encryption and decryption with symmetric cryptographic algorithms 141b described in FIG. 1g below, where a shared secret key can be used to both encrypt/cipher and decrypt/decipher. Symmetric key 127 may also include an expiration time 133, such that symmetric key 127 may only be used by module 101 during a limited period of time, such symmetric key 127 remaining only valid for a day, or a week, or during a session (where the session comprises multiple messages and/or responses

between a module 101 and a server 105), etc. Module 101 can also derive symmetric key 127 according to the Elliptic Curve Integrated Encryption Scheme (ECIES) and/or ECDH 159, discussed in FIG. 1g below, using module public key 111, server public key 114, and a random number from random number generator 128. ECIES could be included in cryptographic algorithms 141. A summary of ECIES shared key derivation is described the Wikipedia article “Integrated Encryption Scheme” from Sep. 18, 2013 (herein incorporated by reference). Other possibilities for shared key derivation function using public keys are possible as well, including a Diffie-Hellman key exchange. Using a derived symmetric key from the exemplary key derivation function ECIES, module 101 could derive a second symmetric key 127 after the expiration time 133 of the first symmetric key 127 had transpired.

Note that a key derivation function using public keys is not required to generate a shared symmetric key 127, and alternatively a shared symmetric key 127 could be generated by any of module 101, server 105, module provider 109, or M2M service provider 108. If module 101 generates shared symmetric key 127 for symmetric ciphering 141b within a cryptographic algorithms 141, then module 101 can send shared symmetric key 127 to server 105 using an asymmetric ciphering depicted and described in connection with FIG. 4 below. In this case, module 101 preferably uses a random number generator 128 to generate a random number 128a (illustrated in FIG. 1g) for input into cryptographic algorithms 141, and the seed 129 in random number generator 128 could utilize data from a sensor 101f in order to generate a random number 128a with high entropy in the creation of symmetric key 127. In exemplary embodiments, random number 128a can also comprise a string output of random number generator 128, and thus random number 128a may be recorded in a format other than a number. Thus, the output of a random number generator 128 can comprise a string in addition to numbers, or the output of random number generator 128 could be a binary number or a series of binary numbers that could be encoded into a string. If server 105 or M2M service provider 108 generates the symmetric key 127, server 105 can send module 101 the symmetric key 127 securely using asymmetric ciphering 141a depicted and described in connection with FIG. 5a and FIG. 1g below.

Module identity 110 is preferably a unique identifier of module 101, and could comprise a number or string such as a serial number, an international mobile subscriber identity number (IMSI), international mobile equipment identity (IMEI), or an Ethernet media access control (MAC) address. According to an exemplary embodiment, module identity 110 can also comprise a serial number or string that is written into hardware of module 101 upon manufacturing or distribution of module 101. In this case, module identity 110 could be recorded in a read only memory 101c, where read only memory 101c could not be easily erased or otherwise tampered with. Or, module 101 could read module identity 110, which could be written into hardware by a manufacturer, distributor, or module provider 109, by using a device driver 101g that reads a hardware address containing the module identity 110 using the bus 101d. Module 101 can read the module identity 110 by accessing a read-only address using the bus 101d. In either case, module identity 110 may preferably be permanently or persistently associated with the physical hardware of module 101, which can be helpful for the security procedures contemplated herein. Module identity 110 can function as a basic identifier for services from M2M service provider 108, server 105, and/or application 171i in order to properly identify module 101

among a plurality of modules. Module private key **112** and module public key **111** could be unique to module **101** and uniquely associated with module identity **110**, according to a preferred embodiment.

As contemplated herein, a module identity **110** can also have more than one use. A first module identity **110** could comprise a serial number for the physical hardware of module **101**, as described in the paragraph above. A second module identity **110** could also comprise a session identifier, for data sessions between module **101** and server **105**, where the session identifier can be uniquely associated by a server **105** to module **101**. In the case where module identity **110** has more than one use, format, or representation, the module identity **110** associated with or written into hardware of module **101** (and potentially read from a read-only address in module **101**) would preferably comprise the module identity **110** used in a certificate **122**. Since a module **101** may utilize multiple module public keys **111** and module private keys **112** over its lifetime, a certificate **122** for module **101** can preferably include both (i) the module identity **110** (such as a serial number for the physical hardware of module **101**) and (ii) a module public key identity **111a** in order to specify the particular module public key **111** associated with certificate **122**. The use of a module public key identity **111a** in a certificate **122** is also described in FIG. **1h** below. Since a module **101** may also have multiple public keys **111** for different purposes (such as one for creating digital signatures, another for asymmetric ciphering, another for use with a second wireless network **102**, etc.), then module **101** may also potentially have multiple valid certificates **122** concurrently.

Further, as contemplated herein, a module identity **110** could also comprise more than one physical string or number, such as a first string when module **101** connects with a first M2M service provider **108** or first wireless network **102**, and module identity **110** could comprise a second string when module **101** connects with a second M2M service provider **108** or second wireless network **102**. The first M2M service provider **108** or first wireless network **102** may have a first requirement or specification for the format, length, structure, etc. of module identity **110**, and the second M2M service provider **108** or second wireless network **102** may have a second requirement or specification for the format, length, structure, etc. of module identity **110**.

Server public key **114** in module **101** could be obtained from downloading the key over the Internet **107**, or optionally also written into nonvolatile memory of module **101** upon manufacture or distribution. Server public key **114** could be obtained using a domain name or Internet address that is recorded in nonvolatile memory upon the configuration of module **101**, such as during installation or distribution, and module **101** could fetch the server public key **114** upon connecting to a wireless network **102** or other connection to the Internet **107**. Server public key **114** can be the public key associated with server **105** or M2M service provider **108**. Although a single server public key **114** is illustrated in FIG. **1e**, module **101** could record a plurality of server public keys **114**, where each server public key **114** is associated with a different server **105**. Server public key **114** can optionally be signed by a certificate authority **118** in FIG. **1a**, such that when module **101** communicates with server **105**, module **101** can verify a signature **123** (shown in FIG. **1h**) within a certificate **122** associated with server **105**. Successful verification of the signature **123** can provide a high level of certainty that server **105** is properly identified and belongs to M2M service provider **108**, as opposed to being an imposter or part of a "man in the middle" attack.

Module **101** may also contain cryptographic algorithms **141**, which may comprise a suite of algorithms or subroutines that can be utilized for (i) deriving a pair of keys comprising a public key and a private key, (ii) encrypting data using public keys, (iii) decrypting data using private keys, (iv) processing secure hash signatures using private keys, and (v) verifying secure hash signatures using public keys, and related software, firmware, or subroutines for implementing a cryptographic system, including symmetric ciphering algorithms. Cryptographic algorithms **141** (also described below in FIG. **1g**) could utilize publicly available software libraries within tools such as OpenSSL maintained by The OpenSSL Project (<http://www.openssl.org/>), libgcrypt maintained by The Free Software Foundation (<http://www.gnu.org/software/libgcrypt/>), and similar libraries such as libmccrypt and Crypto++. Note that cryptographic algorithms **141** could also use proprietary cryptographic libraries as well. In addition to implementing asymmetric encryption/ciphering, such as used with RSA and ECC cryptography, cryptographic algorithms **141** can provide symmetric ciphering where a shared private key is utilized to both encrypt and decrypt, such as with the Advanced Encryption Standard (AES) cipher suite.

As illustrated in FIG. **1e**, module **101** may also contain a random number generator **128**. Random number generator **128** may contain a seed **129**. The creation of random numbers with a high degree of entropy may be important the use of cryptographic algorithms **141**. However, obtaining random numbers with high entropy in module **101** with limited processing resources may be a challenge using conventional technology. Since much of the operation of module **101** requires a CPU **101b** following a pre-determined series of steps, such as the programmatic steps in an operating system **101h**, module program **101i**, etc., the random number generator seed **129** should preferably be populated with data that is close to random "noise" and not subject to replay. According to a preferred exemplary embodiment, module **101** utilizes data input from sensor **101f** and/or radio **101z** into a seed **129** within a random number generator **128**. As one example, the sensor data input into seed **129** could comprise the least significant digits of a sensor measurement or series of sensor measurements, where the least significant digits would otherwise be effectively considered "noise".

In this exemplary embodiment of using a sensor to collect a "noisy" signal for input into a random number generator **128** or seed **129**, if sensor **101f** comprised a temperature measuring device such as a thermocouple or thermistor with a stated accuracy of 0.1 degrees, module **101** could take a series of measurements with 0.0001 degree resolution and utilize the last two digits appended from a series of measurements for input into a seed **129** in order to generate a random number **128a**. Random number generator **128** could also utilize data input from the other components illustrated in FIG. **1e** in order to generate a random number **128a**, where the data input from the other components comprise a signal with a high level of "noise" or high entropy. The seed **129** could comprise multiple seeds **129** or also a random number generator **128** could derive a random number **128a** using input from other components illustrated in FIG. **1e** and without using a seed **129**.

Other possibilities exist as well, such as if sensor **101f** was a camera, module **101** could take a series of pictures and process the image to input data from the image into a seed **129**. Likewise, module **101** could utilize numerous radio-frequency (RF) measurements from radio **101z** in order to populate seed **129**, including "noise" measurements on

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unused frequencies, or other data received by a radio 101z, including apparently random RF data. Although not illustrated in FIG. 1e, module 101 preferably includes a timing source such as a clock, and the clock could also be utilized to input data into a seed 129. Data from radio 101z, a clock (not shown), and/or sensor 101f, and/or radio 101z could be combined in order to input data into a seed 129. Additional input into the seed 129 could include measurements or states within memory 101e and 101w, operating system 101h states and files, and reading data from hardware through a bus 101d. A state can comprise a list or set of constants, variables, values, and/or data at a point in time or over an interval of time.

A plurality of the data as a source for a random number seed 129 could be appended together into a "module random seed file" 139 (illustrated in FIG. 1g) with a combined series or list of states (i.e. a plurality of sensor 101f measurements, radio 101z measurements, clock times, memory 101e or memory 101w states, operating system 101h states, actuator 101y states, and/or hardware 101a or 101d states). Note that values or data for each of the elements listed in the previous sentence could be utilized in a "module random seed file" 139 instead of or in addition to a state. The "module random seed file" 139 can then be input into the secure hash algorithm 141c described in FIG. 1g below, and the output of the secure hash algorithm 141c could then be used in the input as a seed 129 within random number generator 128. Also, this combined data (including in the form of a "module random seed file" 139) could be utilized by random number generator 128 directly in order to process a random number 128a. Other possibilities exist as well without departing from the scope of the present invention.

Note that the term "public key" as contemplated herein includes a key that may be shared with other elements, where the other elements may not be under the direct control of the same entity that holds the corresponding private key. However, the term "public key" as used herein does not require that the public key is made available to the general public or is publicly disclosed. An additional layer of security may be maintained in the present invention by preferably only sharing public keys on a confidential basis with other entities. For example, module public key 111 may be created by module 101 when generating module private key 112, and module 101 may share module public key 111 with M2M service provider 108 in order to record module public key 111 in server 105, but module 101 could choose to not share module public key 111 with other entities, such as wireless network 102 or make a certificate 122 with module public key 111 available on the Internet 107. The benefits of confidentially sharing module public key 111 with server 105 are also further described in connection with FIG. 10 below.

Although a single public key and private key for (i) module 101 and (ii) server 105 are illustrated in FIG. 1e and also FIG. 1f below, respectively, both module 101 and server 105 may each utilize several different pairs of public keys and private keys. As one example, module 101 may record a first private key 112 used for creating a digital signature and a second private key 112 for decryption using asymmetric ciphering algorithms 141a. In this example, a server 105 could utilize a first module public key 111 to verify the digital signature, and a second module public key 111 could be utilized to encrypt messages sent to module 101. Similarly, either module 101 or server 105 may use private key 112 or 105c, respectively, to derive secondary shared keys such as a derived shared key 129b below. Thus, one key pair could be used with digital signatures, a second key pair used

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for asymmetric ciphering, and a third key pair to derive shared secret keys. Each of the three illustrated pairs of keys could comprise a set of keys, and each of the illustrated pairs of keys could also use a different set of parameters 126, although the parameters 126 for the various pairs of keys could also be the same.

In addition, module 101 could utilize a first set of keys to communicate with a first server 105 and a second set of keys to communicate with a second server 105. The first set of keys could use or be associated with a first set of parameters 126 and the second set of keys could use or be associated with a second set of parameters 126. Likewise, M2M service provider 108 illustrated in FIG. 1a could utilize a first pair of secondary private and public keys with a first server 105, and a second pair of secondary private and public keys with a second server 105. As contemplated herein, the term "private key" can also refer to secondary non-shared keys derived from a "parent" private key such as key 112 or key 105c, and the term "public key" can also refer to (i) secondary, shared keys derived using a private key such as key 112, or (ii) secondary, shared keys associated with a public key such as key 111. Other possibilities exist as well for a key to represent derived or associated keys without departing from the scope of the present invention.

According to exemplary embodiments, module 101 may also include a pre-shared secret key 129a. Pre-shared secret key 129a can comprise a secret key that is shared between module 101 and server 105 before module 101 begins (i) communicating with server 105 and/or a certificate authority 118, (ii) or utilizing PKI-based encryption and authentication to communicate with M2M service provider 108. As illustrated in FIG. 1f below, server 105 could also record the pre-shared secret key 129a, and a pre-shared secret key 129a can be associated with each module 101 using a module identity 110. A pre-shared secret key 129a could be a secure key comprising a string or number loaded into a nonvolatile memory 101w of module 101 by a manufacturer, distributor, installer, or end user of module 101. Pre-shared secret key 129a can be moved by CPU 101b from the nonvolatile memory 101w into a RAM 101e for further processing during the use of cryptographic algorithms 141.

Note that pre-shared secret key 129a can be different than a pre-shared secret key used with conventional technology such as SIM cards in PLMN networks, such as the key Ki, where the pre-shared secret key in a SIM card is designed to not be available for movement or loading into a RAM 101e for processing by CPU 101b. Alternatively, pre-shared secret key 129a could be derived using a second pre-shared secret key Ki within a SIM card, but then server 105 would need to be able to derive the same pre-shared secret key 129a, even though server 105 may not have pre-shared secret key Ki available. Although not shown in FIG. 1e, a module 101 may also include a SIM card that includes a pre-shared secret key 129a, wherein the pre-shared secret key 129a in a SIM card is different than pre-shared secret key Ki, since the pre-shared secret key in the SIM card cannot be moved into RAM 101e for processing with a cryptographic algorithms.

Pre-shared secret key 129a as illustrated in FIG. 1e can be loaded by a manufacturer, distributor, installer, or end user of module 101 using a physical interface 101a, such as (i) a USB interface 101v, or (ii) a local WiFi network if module 101 includes a WiFi client. Pre-shared secret key 129a may optionally be uniquely bound to module identity 110, such that another module 101 with a different module identity 110 could not utilize pre-shared secret key 129a. Or, pre-shared secret key 129a could be used by any module 101, but only

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used one time and thus a second module 101 could not utilize the exact same key within a pre-shared secret key 129a for authentication with server 105 at a subsequent time. Alternatively, pre-shared secret key 129a could be shared by a plurality of modules 101, and for example compiled into a module program 101i, such that multiple modules utilize the same pre-shared secret key 129a.

Pre-shared secret key 129a could be obtained by a distributor, installer, or end user of module 101 by (i) using a local computer to access a web page from a web portal 171j, where the web page can be user password protected, (ii) entering, submitting, or typing information including a module identity 110 into the web page, and subsequently (iii) downloading pre-shared secret key 129a from the web portal 171j. A different web server could be utilized besides the web portal 171j illustrated in FIG. 1d. The web server could be operated by an entity such as module provider 109, M2M service provider 108, or even certificate authority 118 (since pre-shared secret key 129a could be used to authenticate the submission of module public key 111). Note that the pre-shared secret key 129a could also be presented visually on a response web page to the submission, and the a manufacturer, distributor, installer, or end user could record the pre-shared secret key 129a visually presented on the response web page. Pre-shared secret key 129a could comprise a string of an exemplary set of characters or numbers such as 10-16 digits or characters, although other lengths for pre-shared secret key 129a could be possible as well.

According to a preferred exemplary embodiment, in order to obtain the pre-shared secret key 129a from a web page as described in the above paragraph, the distributor, installer, or end user of module 101 could read a pre-shared secret key code 134. Pre-shared secret key code 134 could be physically printed on module 101, such as next to a serial number printed on the enclosure of the device. Pre-shared secret key code 134 could be a unique and/or randomized string such as an exemplary 8 byte number or 10 character string (and other possibilities exist as well), where upon (a) successful submission to a web page of both the pre-shared secret key code 134 with a module identity 110, then (b) the release of pre-shared secret key 129a would be authorized for the distributor, installer, or end user of module 101. Pre-shared secret key 129a could be transmitted through a secure web session such as SSL or TLS from a web portal 171j to a computer operated by the distributor, installer, or end-user. The distributor, installer, or end-user could then load the pre-shared secret key 129a into the nonvolatile memory of the module using (i) a LAN connection such as WiFi to the module (and in this case radio 101z in module 101 could support an 802.11 type connection) or (ii) a USB interface 101v.

Pre-shared secret key 129a could be utilized by a module 101 (i) as a shared secret key 510 in FIG. 5b, or (ii) to derive a shared secret key 510 also recorded by a server 105 in FIG. 5b below. Note that module program 101i preferably includes a verification process for any pre-shared secret key 129a loaded by a distributor, installer, or end user, where a hash value or combination of the pre-shared secret key 129a and module identity 110 could be verified. As one example, the last few digits or characters in a pre-shared secret key 129a could comprise a checksum for a string comprising both module identity 110 and pre-shared secret key 129a, such that module 101 could calculate the checksum after entry of pre-shared secret key 129a, and module 101 can reject the pre-shared secret key 129a if the checksum failed. In this manner, or through the use of similar techniques, system 100 can be designed so that pre-shared secret key

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129a can only reasonably be utilized by a correct module 101 with the correct module identity 110 for the pre-shared secret key 129a.

Since module 101 may have multiple module identities 110, a first module identity 110 could be used with a pre-shared secret key code 134 and printed on an enclosure of module 101, while a second and more secure (i.e. longer length or more randomized bits) module identity 110 could be used as a module identity 110 in a message 208 as described in FIG. 2 below. Note that when using the exemplary embodiment illustrated in FIG. 5b below, (x) the module identity 110 submitted with a web page and pre-shared secret key code 134 is preferably different than (y) an unencrypted module identity 110 within a message 208 illustrated in FIG. 6a and FIG. 6b. A module identity 110 submitted by a distributor, installer, or end user in a web page could preferably be easy to manually type into a web page, such as 10 or 12 decimal digits or characters, while an unencrypted module identity 110 within a message 208 could be significantly longer, such as 16 or 24 extended ASCII characters, and other possibilities exist as well without departing from the scope of the present invention.

Application server 171 running web portal 171j could (i) record a table of triplets including module identities 110, pre-shared secret key codes 134, and pre-shared secret keys 129a, and (ii) return via a web page the pre-shared secret key 129a upon a successful match and entry of the submitted pre-shared secret key code 134 and module identity 110. Once the pre-shared secret key 129a has been utilized to authenticate or verify a module public key 111 with a server 105 (such as using subsequent steps 517 in FIG. 5b below), then that particular pre-shared secret key 129a may be “discarded” and not used again for security purposes contemplated herein. After module 101 obtains an initial secure connection to server 105, using the techniques illustrated in FIG. 3 through FIG. 6b, then server 105 can securely send keys for use with future communication including a symmetric key 127 or other shared secret keys for authorizing any subsequent submission of a new module public key 111 with module identity 110 by module 101 in a step 517 illustrated in FIG. 5b.

Note that the use of a pre-shared secret key 129a and pre-shared secret key code 134 is also optional, such that a module program 101i could cipher or obfuscate the initial submission of a derived module public key 111 and module identity to a server 105, so that server 105 could be reasonably assured only a valid module 101 submitted the module public key 111. Alternatively, the module manufacturer could load the pre-shared secret key 129a in non-volatile memory such as flash 101w upon manufacturing, and in this case a distributor, installer, or end-user may not need to access or load the pre-shared secret key 129a. However, the steps for a distributor, installer, or end-user to read a pre-shared secret key code 134 and submit the code to a web portal 171j to obtain pre-shared secret key 129a may still be useful, such as if module 101 needs the equivalent of a “factory reset” after deployment, reconfiguration such as loading new firmware, or otherwise reset or returned to a default state.

Although (A) a pre-shared secret key 129a may be useful for sending module public key 111 to server 105 or other entities connected to the Internet 107, such as a certificate authority 118, (B) pre-shared secret key 129a could be used for other purposes as well, such as input into a key derivation function 141f shown in FIG. 1g so that module 101 and server 105 could obtain common derived shared secret keys 129b. In this case, a derived shared secret key 129b could be

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utilized as a shared secret key **510** depicted and described in connection with FIG. **5b** below. In addition, after the first use of pre-shared secret key **129a**, a manufacturer, distributor, installer, or end user may also upload a second pre-shared key **129a** into module **101** at a future date, such as upon reconfiguration of a module **101**.

According to a preferred exemplary embodiment, module **101** can derive its own module private key **112** and module public key **111**, and utilize pre-shared secret key **129a** in order to securely and/or authoritatively communicate the derived module public key **111** with server **105** and/or a certificate authority **118**. The use of pre-shared secret key **129a** can be particularly useful if module **101** has already been deployed with a monitored unit **119** and connects to server **105** through the Internet **107** for the very first time. Server **105** could preferably utilize pre-shared secret key **129a** in order to confirm that a received module public key **111** and module identity **110** from module **101** authoritatively belong to module **101**, as opposed to being an unauthorized or even fraudulent submission of module public key **111** and module identity **110**.

Server **105** could utilize a pre-shared secret key **129a** and the steps depicted and described in connection with FIG. **4** below in order to securely receive module public key **111** and module identity **110** from module **101**, including the first time module **101** sends module public key **111** to server **105**. As one example, pre-shared secret key **129a** could be utilized as a symmetric ciphering **141b** key, described in FIG. **1g** below. After the first submission of module public key **111** to server **105**, any subsequent submissions of new module public keys **111** derived by module **101** could either (i) continue to use the pre-shared secret key **129a**, or (ii) use a symmetric key **127** derived after the first module public key **111** has been received. Securing the submission of module public key **111** with server **105**, including both the first submission and subsequent submissions, is also depicted and described in connection with FIG. **5b** below.

FIG. **1f**

FIG. **1f** is a graphical illustration of the components within a server, in accordance with exemplary embodiments. Server **105** can include a module database **105k**, a sub-server **105w**, and a message preprocessor **105y**. In an exemplary embodiment, the elements illustrated within a server **105** in FIG. **1f** may be stored in volatile memory such as RAM **105e**, and/or storage **105m**, and may also be accessible to a processor CPU **105b**. In another exemplary embodiment, the module database **105k**, sub-server **105w**, and message processor **105y** can comprise separate computers. Module database **105k**, sub-server **105w**, and message preprocessor **105y** could represent either different processes or threads operating on a server **105**, or physically separate computers operating in conjunction over a network to perform the functions of a server **105**. Since server **105** can preferably support communications with a plurality of modules **101**, server **105** can utilize module database **105k** to store and query data regarding a plurality of modules **101**, monitored units **119**, and the overall M2M service. The server **105** can store a plurality of module public keys **111** associated with a plurality of devices in the module database **105k**. The server **105** can use the module identity **110** of device **101**, received in a message such as a UDP packet, to query the module database **105k** and select the public key **111** or symmetric key **127** associated with the module **101**.

Although not illustrated in FIG. **1f**, module database **105k** can also record a pre-shared secret key code **134**, a set of parameters **126**, and a module identity **110** for each module **101**, along with the pre-shared secret key **129a** shown in

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FIG. **1f**. In addition, although not illustrated in FIG. **1f**, module database **105k** could store a symmetric key **127** for each module **101**, if cryptographic algorithms **141** utilize a symmetric cipher **141b** such as AES for communication with module **101**. Examples of module database **105k** could include MySQL, Oracle®, SQLite, hash tables, distributed hash tables, text files, etc. Module database **105k** could reside within RAM **105e** or storage **105m**. Server **105** may also record a symmetric key **127**, where the symmetric key **127** can be associated with an expiration time **133**. Symmetric key **127** can also be recorded in a module database **105k** or a sub-server **105w**.

Message preprocessor **105y** can process incoming packets and route them to an appropriate sub-server **105w** using information contained in an incoming message, such as a module identity **110**, a server identity **206** illustrated in FIG. **2** below, and/or a destination IP address. Message preprocessor **105y** can include rules for processing and routing, such as dropping malformed incoming messages or incoming messages without correct cryptographic data. Message preprocessor **105y** could also optionally be combined with a server firewall **124** in order to provide firewall functionality and security at the network layer. Message preprocessor **105y** may preferably remain "silent" to incoming packets without proper cryptographic data contained in an incoming message, such as one example of a properly formatted message **208** illustrated in FIG. **6a** below.

Sub-server **105w** can include a server private key **105c** and cryptographic algorithms **141**. A plurality of sub-servers **105w** can be utilized by a server **105** in order to support communication with a plurality of wireless modules **101**. The server private key **105c** and module public key **111** can be utilized by server **105** to secure communication with module **101**, including the steps depicted and described in connection with FIG. **4** and FIG. **5a** below. Cryptographic algorithms **141** may comprise a suite of algorithms or subroutines and can be utilized for (i) encrypting data using public keys, (ii) decrypting data using private keys, (iii) processing secure hash signatures using private keys, and (iv) verifying secure hash signatures using public keys.

A first sub-server **105w** can process messages and responses with a first module **101** using a first set of security keys and algorithms, such as using RSA-based security, and a second sub-server **105w** can process messages and responses with a second module **101** using a second set of security keys and algorithms, such as using ECC-based security. Consequently, message pre-processor **105y** could route incoming messages to the appropriate sub-server **105w** depending on the encryption algorithm used in the incoming message (which could be determined by message pre-processor **105y** by querying the module database **105k** using a module identity **110** in the incoming message **208**). Sub-servers **105w** may utilize separate server private keys **105c**, or the sub-servers **105w** can share a common private key **105c**. Sub-servers **105w** may utilize separate cryptographic algorithms **141**, or the sub-servers **105w** can share common cryptographic algorithms **141**. Although separate sub-servers **105w** are illustrated in FIG. **1f**, the sub-servers may optionally be combined with a server **105**, or omitted, with the corresponding server private key **105c** and cryptographic algorithms **141** stored directly in a server **105**.

Server **105** may also comprise a collection of individual computers, where the individual computers could be either centrally located or geographically dispersed, but the individual computers may function in a coordinated manner over a network to operate as a server **105**. Server **105** may

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be a “virtualized” server, with computing resources shared with other processes operating on a computer.

FIG. 1g

FIG. 1g is a graphical illustration of the components in a set of cryptographic algorithms, in accordance with exemplary embodiments. As contemplated herein, communications between (i) a module 101 and a server 105, and (ii) between application 171i and server 105 can be secured by using cryptographic algorithms 141. The cryptographic algorithms 141 used by module 101, server 105, application server 171, and/or application 171i can comprise a set of steps, procedures, or software routines for accomplishing steps to cipher, decipher, sign, and verify messages, including the generation of public keys, private keys, and derived shared keys. Cryptographic algorithms 141 can be implemented in software operating on (i) module 101 in the form of a module program 101i, (ii) server 105 in the form of a module controller 105x, or (iii) application server 171 in the form of an application 171i. Example software for a cryptographic algorithms 141 includes the libraries within the openssl, libmbedtls, and/or and Crypto++ discussed in FIG. 1e. Other possibilities for the location of cryptographic algorithms within a module 101, server 105, or application 171i exist as well, including possibly module operating system 101h, server operating system 105h, and application server operating system 171h, respectively.

In addition, cryptographic algorithms 141 may be implemented in hardware or firmware on any of module 101, server 105, or application 171i. Note that module 101, server 105 and application 171i could each utilize a different set of cryptographic algorithms 141, although the sets of algorithms should preferably be fully interoperable (i.e. ciphering with a first symmetric ciphering algorithm 141b and a symmetric key 127 on module 101 could be deciphered by a second symmetric ciphering algorithm 141b on server 105 using the symmetric key 127, etc.). As illustrated in FIG. 1g, cryptographic algorithms 141 may comprise an asymmetric ciphering algorithm 141a, a symmetric ciphering algorithm 141b, a secure hash algorithm 141c, a digital signature algorithm 141d, a key pair generation algorithm 141e, a key derivation function 141f, and a random number generator 128.

Asymmetric ciphering algorithms 141a can comprise algorithms utilizing public key infrastructure (PKI) techniques for both (i) encrypting with a public key and (ii) decrypting with a private key. Example algorithms within asymmetric algorithms 141a include the RSA algorithms 153 and the Elliptic Curve Cryptography (ECC) algorithms 154, and other asymmetric algorithms could be utilized as well. For example, either the ECC algorithms 154 or RSA algorithms 153 can be used for encryption and decryption, including (i) encryption element 503 discussed below, as well as (ii) decryption element 413 discussed below. A set of parameters 126 can include input into asymmetric ciphering algorithms 141a, such as specifying key lengths, elliptic curves to utilize (if ECC), modulus (if RSA) or other parameters or settings required. As contemplated herein and described in additional detail below, the algorithms illustrated in FIG. 1g can perform both ciphering and deciphering, using the appropriate keys.

The use and application of RSA algorithms and cryptography are described within IETF RFC 3447 titled “Public-Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1”, herein incorporated by reference, among other published standards for the use of RSA algorithms 153. The use of an RSA algorithm 153 for encryption and decryption, including with cryptographic

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algorithm and other description of encryption or decryption algorithms, can also be processed according to the description of the RSA algorithm according to the Wikipedia entry for “RSA (algorithm)” as of Sep. 9, 2013, which is incorporated by reference herein.

The use and application of ECC algorithms 154 for asymmetric ciphering algorithms 141a within cryptographic algorithms 141 are described within IETF RFC 6090 titled “Fundamental Elliptic Curve Cryptography Algorithms” (herein incorporated by reference), among other published standards using ECC. ECC algorithms 154 can also utilize elliptic curve cryptography algorithms to the Wikipedia entry for “Elliptic curve cryptography” as of Sep. 9, 2013, which is incorporated by reference herein. ECC algorithms 154 may be utilized according to exemplary preferred embodiments in order to maintain high security with smaller key lengths, compared to RSA, thereby helping to comparably reduce the message lengths, radio frequency spectrum utilization, and processing power required by module 101. Thus, the use of ECC algorithms 154 within various steps requiring ciphering or digital signatures may help conserve battery life of module 101 while maintaining the objective of securing system 100. Note that as contemplated herein, other algorithms besides with ECC algorithms 154 and RSA algorithms 153 may be also be used in asymmetric algorithms 141a.

Cryptographic algorithms 141 may also include a set of symmetric ciphering algorithms 141b. Symmetric ciphering algorithms 141b can utilize a symmetric key 127 by one node such as a module 101 to encrypt or cipher data, and the encrypted data can be decrypted or deciphered by server 105 also using the symmetric key 127. Examples of symmetric ciphers include Advanced Encryption Standard 155 (AES), as specified in Federal Information Processing Standards (FIPS) Publication 197, and Triple Data Encryption Standard (Triple DES), as described in NIST Special Publication 800-67 Revision 1, “Recommendation for the Triple Data Encryption Algorithm (TDEA) Block Cipher (Revised January 2012)”. Parameters 126 input into symmetric ciphering algorithms 141b can include symmetric key 127 length, such as the selection of 128, 192, or 256 bits with AES 155 symmetric ciphering, and parameters 126 could also select a symmetric ciphering algorithm in a collections of symmetric ciphering algorithms 141b. Other examples of symmetric ciphering algorithms 141b may be utilized as well within cryptographic algorithms 141. Also note that as contemplated herein, the term “symmetric ciphering” contemplates the use of a symmetric ciphering algorithm 141b in order to encrypt or cipher data with a symmetric ciphering algorithm 141b, and “asymmetric ciphering” contemplated the use of an asymmetric ciphering algorithm 141a to encrypt or cipher data with a public key, such as module public key 111 or server public key 114.

Cryptographic algorithms 141 may also include a set of secure hash algorithms 141c in order to compute and output a secure hash value or number based on a string or file input into the secure hash algorithms 141c. Example secure hash algorithms include SHA256 156 (also known as SHA-2) and SHA-3 157. SHA256 156 is specified in the National Institute of Standards and Technology (NIST) Federal Information Processing Standards Publication (FIPS PUB) 180-2 titled “Secure Hash Standard”. SHA-3 157 is scheduled to be published in FIPS PUB 180-5. Parameters 126 input into secure hash algorithms 141c can include the selection of the length of the secure hash, such as using 224, 256, or 512 bits with either SHA-2 or SHA-3, and other possibilities exist as well.

Cryptographic algorithms **141** may also include a set of digital signature algorithms **141d**, in order to sign and verify messages between (i) module **101** and server **105** or (ii) server **105** and application **171i**. Digital signature algorithms **141d** can also verify signatures such as comparing that (i) a first secure hash value in the form of a digital signature in a certificate (not shown) using a certificate authority public key **132** matches (ii) a second secure hash value in the certificate (not shown). Digital signature algorithms **141d** can utilize algorithms in National Institute of Standards (NIST) "FIPS 186-4: Digital Signature Standard", or IETF RFC 6979 titled "Deterministic Usage of the Digital Signature Algorithm (DSA) and Elliptic Curve Digital Signature Algorithm (ECDSA)". The use of ECDSA algorithm **158** within a set of digital signature algorithms **141d** may be preferred if keys such as module public key **111** and server public key **114** are based on elliptic curve cryptography. Other PKI standards or proprietary techniques for securely verifying digital signatures may be utilized as well in digital signature algorithms **141d**. Parameters **126** input into digital signature algorithms **141d** can include the selection of a secure hash algorithms **141c** to utilize with digital signature algorithms **141d**, or the algorithm to utilize, such as ECDSA shown or an RSA-based alternative for digital signatures is possible as well. Parameters input into digital signature algorithms **141d** can also include a padding scheme for use with a digital signature algorithms **141d**. Digital signature algorithms **141d** could also include an RSA digital signature algorithm for use with RSA-based public and private keys.

Cryptographic algorithms **141** may also include key pair generation algorithms **141e**, a key derivation function **141f**, and a random number generator **128**. Key pair generation algorithms **141e** can be utilized by module **101**, server **105**, or application **171i** to securely generate private and public keys. The key pair generation algorithms **141e** can also use input from a parameters **126**, such as the desired key lengths, or an ECC curve if the public key will support ECC algorithms **154**. According to an exemplary preferred embodiment, module **101** can derive a pair of module public key **111** and module private key **112** using key pair generation algorithms **141e**. Software tools such as openssl and libcrypto include libraries for the generation key pairs, and these and similar libraries can be used in a key pair generation algorithm **141e**.

Key derivation function **141f** can be used by module **101**, server **105**, and/or application **171i** in order to determine a common derived shared secret key **129**, using at least two respective public keys as input, and may also include the input of a private key. A key exchange to share a common symmetric key **127** can be performed using a key derivation function **141f** and parameters **126**. An exemplary algorithm within a key derivation function **141f** can be the Diffie-Hellman key exchange, which is used by tools such as secure socket layer (SSL) with RSA algorithms **153**. When using ECC algorithms **154**, module **101** and server **105** can utilize Elliptic Curve Diffie-Hellman (ECDH) algorithms **159**, and a summary of ECDH is included in the Wikipedia article titled "Elliptic Curve Diffie-Hellman" (http://en.wikipedia.org/wiki/Elliptic_curve_Diffie-Hellman) from Sep. 24, 2013, which is herein incorporated by reference. Other algorithms to derive a shared secret key **129b** using public keys and a private key may also be utilized in a key derivation function **141f**, such as the American National Standards Institute (ANSI) standard X-9.63 160. Parameters **126** used with key derivation function **141f** with elliptic curve cryptography can include a common base point **G** for two node using the key derivation

function **141f** and public keys. The base point **G** in a parameters **126** can be transmitted or sent from a module **101** to a server **105** in a message **208**, and the base point **G** can be sent from a server **105** to a module **101** in a response **209**, and other possibilities exist as well. Parameters **126** can also include other or additional information for using a key derivation function **141f** in order to derive a commonly shared symmetric key **127**.

Parameters **126** input into key pair generation algorithms **141e** can include the type of asymmetric ciphering algorithms **141a** used with the keys, the key length in bits, an elliptic curve utilized for ECC, a time-to-live for a public key that is derived, and similar settings. Additional parameters **126** for a public key can include a supported point formats extension, where the supported point formats extension could comprise uncompressed, compressed prime, or "compressed char2" formats, as specified in ANSI X-9.62. In other words, an ECC public key can have several formats and a set of parameters **126** can be useful to specify the format. Although a set of parameters **126** is illustrated in FIG. 1g as internal to cryptographic algorithms **141**, parameters **126** could be recorded in other locations in a module **101** or a system **100**. As one example, parameters **126** could be recorded in a server **105** and downloaded by module **101** using the Internet **107**. The various algorithms within cryptographic algorithms **141** may utilize a random number generator **128**, which is also depicted and described in connection with FIG. 1e above.

According to a preferred exemplary embodiment, parameters **126** can include values to define an elliptic curve and/or use ECC algorithms **154**. The values could be constants or variables in a defining equation for an elliptic curve, or the parameters could simply name an existing, defined curve such as the standard named curve illustrated in parameters **126** in FIG. 1h. Parameters **126** could include a set of ECC parameters **137** for using elliptic curve cryptography in ECC algorithms **154**, where the ECC parameters **137** can include the ECC parameters in section 3.3 of IETF RFC 6090, including: (i) a prime number **p** that indicates the order of a field **F_p**, (ii) a value "a" used in a curve equation, (iii) a value "b" used in the curve equation, (iii) a generator "g" of the subgroup, and (iv) an order "n" of the subgroup generated by "g". Further, the ECC parameters **137** could include values used for elliptic curve cryptography as specified in IETF RFC 5639 titled "Elliptic Curve Cryptography (ECC) Brainpool Standard Curves and Curve Generation", section 3: (i) a "p" value for the prime specifying the base field, (ii) "A" and "B" are coefficients for an equation such as $y^2 = x^3 + Ax + B \pmod p$ defining the elliptic curve, (iii) "G"=(x,y) as the base point, i.e., a point in **E** of prime order, (iv) "q" as the prime order of the group generated by **G**, and (v) "h" as the cofactor of **G** in **E**, i.e., $\#E(GF(p))/q$. Other possibilities exist as well for an ECC parameters **137** that can be used in a cryptographic algorithms. Parameters **126** could also include an ECC standard curve **138**, which could comprise a name and/or values for a standardized curve, such as the list of named curves included in section 5.1.1 of IETF RFC 4492 titled "Elliptic Curve Cryptography (ECC) Cipher Suites for Transport Layer Security (TLS)."

As contemplated herein, a set of cryptographic algorithms **141** may operate using either strings or numbers, and parameters **126** could include either strings or numbers as well. The processing of cryptographic algorithms within a module **101** can take place within a CPU **101b**, or module **101** could also process cryptographic algorithms in a cryptographic processing unit (not shown) connected to the system bus **101d**. According to an exemplary embodiment,

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a module 101 or a server 105 could include a cryptographic processing unit (not shown) separate from the CPU 101b in order to speed cryptographic computations and/or reduce energy required for supporting the use of cryptography through a system 100. Alternatively, cryptographic algorithms can be implemented entirely in software within a module 101 and/or server 105.

FIG. 1h

FIG. 1h is an illustration of a certificate that includes a PKI public key, where the key comprises an elliptic curve cryptography key, in accordance with exemplary embodiments. Public and private keys in system 100 can utilize PKI techniques other than RSA, such as the elliptic curve cryptography (ECC) public key 111 illustrated in FIG. 1h. One benefit of using ECC is that an equivalent level of security can be obtained for a much smaller key length. Also, energy may be conserved using ECC algorithms 154 compared to RSA algorithms 153. An analysis of the energy conserved for ciphering, deciphering, signing, and verifying messages using ECC versus RSA is included in the paper titled "Energy Analysis of Public-Key Cryptography on Small Wireless Devices" by Wander et al (herein incorporated by reference). Smaller key lengths save bandwidth, memory, processing resources, and power, which are all valuable for a module 101 to conserve a battery 101k and usage of radio-frequency spectrum. For example, an ECC key length of 283 bits provides security similar to an RSA key length of approximately 2048 bits. Module public key 111 can comprise an ECC key in an X.509 certificate, as illustrated in FIG. 1h. Another benefit of using ECC algorithms 154 is that many different defining equations for elliptic curves could be utilized, and the defining equations could also be kept confidential, such that a defining equation for an elliptic curve used in ECC algorithms may optionally be omitted from a certificate 122. In this case, if a public key such as module public key 111 is recorded in a certificate 122, a name or identifying value for the elliptic curve used with a public key could be recorded in a certificate 122, but the underlying defining curve for an elliptic curve could remain confidential. The values to determine an elliptic curve defining equation could be stored in a parameters 126, and the defining equation could also optionally be disclosed.

Certificate 122 could include a signature 123, where signature 123 can be signed using ECC signature techniques, such as the Elliptic Curve Digital Signature Algorithm (ECDSA) 158 with a secure hash such as SHA256 156. In order to generate signature 123, the private key associated with either CA 118 or module provider 109 may also be an ECC-based private key. Note that the public key 111 in a certificate 122 could use a different asymmetric ciphering algorithm 141a than the algorithm used for signing, such that the public key 111 can be an ECC key, while the signature 123 could be generated with RSA algorithm 153 and/or key. Certificate 122 may also include parameters 126, where parameters 126 can specify an elliptic curve utilized with the module public key 111. Parameters 126 could also include the start and end times for the validity of either public key 111 or certificate 122. Other parameters 126 can be utilized in a certificate 122 as well, and a parameters 126 may specify values that are not included or external to a certificate 122.

Certificate 122 illustrated in FIG. 1h also illustrates an exemplary embodiment of the present invention. Over the lifetime of a module 101, which could be a decade or longer, multiple module public keys 111 may be utilized. The potential use of multiple different module public keys 111 include (i) the expiration of a certificate 122 (including

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expiration of a public key associated with a certificate authority used in signature 123), (ii) a need to change an elliptic curve specified in a parameters 126, (iii) adding a new public/private key pair for connection with a different wireless network 102, (iv) as increasing a key length utilized in a public/private key pair, (v) the transfer of ownership or control of module 101, and/or (vi) module 101 connecting to a new server that utilizes a different asymmetric ciphering algorithm (i.e. RSA instead of ECC). Other possibilities exist as well for reasons a module to derive a new module public key 111. Note that the multiple module public keys 111 may also be utilized concurrently, such that (i) a first module public key 111 in a first certificate 122 can be utilized with a first server 105, and (ii) a second module public key 111 (possibly derived using a different set of parameters 126 including using a different elliptic curve) can be utilized with a second server 105 and/or wireless network 102.

In either case of (i) module 101 using multiple module public keys 111 concurrently, or (ii) module 101 using different module public keys 111 in sequence, a certificate 122 can preferably include a module public key identity 111a to specify the module public key 111 utilized in a certificate 122. As illustrated in FIG. 1a, the module public key identity 111a could be included in the "Common Name" (CN) field, and the module identity 110 can be included in the "Organizational Unit" (OU) field. Alternatively, the module public key identity 111a and module identity 110 can be appended together and used in the CN field. In this manner and according to preferred exemplary embodiments, a module public key identity 111a is utilized with both a module identity 110 and a module public key 111 within a certificate 122. Also, as noted previously herein, the use of a certificate 122 may optionally be omitted, such that module 101 and server 105 share public keys without using certificates 122. The module identity 110, or a value associated with the module identity 110 can also be included in certificate 122, such as the "Common Name" (CN) field of a X.509 certificate 122, as illustrated in FIG. 1h.

Note that the use of a certificate 122 is not required for the format of a public or shared key, and the public keys could optionally omit a signature from a certificate authority 118. In this case, the public keys such as module public key 111 and/or server public key 114 could be recorded in the format of a string, without the additional fields illustrated in FIG. 1h. Server public key 114 may also be recorded in a certificate 122 with a signature 123 from a certificate authority 118. Other possibilities exist as well without departing from the scope of the present invention.

FIG. 1i

FIG. 1i is a graphical illustration of an exemplary system that includes a user, an application, a set of servers, and a set of modules, in accordance with exemplary embodiments. System 199 illustrated in FIG. 1i can include a user 183, an application 171i, a set of servers 105, and a set of modules 101, which can communicate as illustrated using the Internet 107. Each of a server 105 A and server 105 B and additional servers can communicate with a plurality of modules. An application 171i can communicate with a plurality of servers 105. Although the servers 105 an application 171i in system 100 in FIG. 1i are illustrated as being separate, application 171i and server 105 may optionally be combined into a single node, such that the application 171i and server 105 operate as separate processes or programs on the same computer, or on a computer operating in a distributed environment such as a cloud configuration. In addition, even though a single application 171i and a single user 183 are

illustrated in FIG. 1*i*, a system 199 could include multiple applications 171*i* and multiple users 183.

User 183 can comprise an individual, business manager, network engineer, systems administrator, other employee with functional responsibilities for a system 199 (or components within a system 199 or system 100) accessing application 171*i* using a computer with a user interface such as a web browser 183*a*. Application 171*i* could also send an email or text message to user 183 if an alarm condition is detected in system 199, such as if a sensor 101*f* measurement exceeds a prescribed threshold value. The web browser 183*a* could use a connection 184 to access a web portal 171*j* operating on application 171*i*. Connection 184 could include hypertext markup language (HTML) messages, and could be through a secure connection such as TLS or IPsec, although other possibilities exist as well to those of ordinary skill in the art. Any module 101, such as Module 101 A, could use the Internet 107 and establish a primary connection 181 with server 105 A, and also module 101 A could establish a backup connection 182 with server 105 B if the primary connection 181 is not available. Alternatively, any module 101, such as module 101 A, could communicate with more than one server 105 concurrently or in sequence, such that module 101 A communicates with both server 105 A and server 105 B. According to exemplary embodiments, during an active state between periods of sleep or being dormant, module 101 may communicate with more than one server 105, such as a first server 105 A and a second server 105 B. Other possibilities for a plurality of modules 101 to communicate with a plurality of servers 105 exist without departing from the scope of the present invention.

FIG. 2

FIG. 2 is a graphical illustration of an exemplary system, where a module sends a message to a server, and where the server responds to the message, in accordance with exemplary embodiments. Module 101 as depicted and described in FIG. 2 can operate as a wireless module 101, although a wired connection to the Internet 107 could alternatively be utilized. System 100 as illustrated in FIG. 2 includes RF signals 201, module IP address 202, port number 203, module IP:port 204, server port number 205, server ID 206, server IP:port number 207, message 208, response 209, wireless network firewall address 210, and firewall port binding packet 211. Many of the elements illustrated within system 100 in FIG. 2 are also depicted and described in connection with FIG. 2 of U.S. patent application Ser. No. 14/039,401 (the contents of which are hereby incorporated by reference in their entirety). As contemplated herein, a wireless module 101 can comprise a module 101, or in other words a wireless module 101 may be a module 101 that is wireless. Functions described as being performed by a wireless module 101 may also be performed by a wired module 101 (where connection to a wired network would be used instead of connection to a wireless network 102). Also as contemplated herein and illustrated in FIG. 2, the wording “module 101 sends a message 208” can also be considered equivalent to “server 105 receives a message 208”. Likewise, the wording “server 105 sends a response 209” can be considered equivalent to “module 101 receives a response 209”.

A wireless module 101 can wake from a dormant state in order perform (i) remote and automated monitoring and (ii) control functions such as collecting a sensor 101*f* measurement, communicating with server 105, and controlling an actuator 101*y*. If module 101 is connected to land-line power or a long-lasting external power source such as solar power, then module 101 may remain in an active state and bypass

a dormant state, although transmitting RF signals 201 may preferably only be utilized when communicating with wireless network 102 or sending data to and receiving data from server 105. Upon waking from the dormant state and starting communication with a server 105, a wireless module 101 can begin transmitting RF signals 201 to base station 103. The wireless module can acquire an IP address 202 from the wireless network 102. IP address 202 is illustrated as being an IPv6 address, but IP address 202 could also be an IPv4 address. IP address 202 could also be a subset of IPv6 addresses such as the last 32 or 64 bits in a full 128 bit IPv6 address, and wireless network 102 could append the beginning 96 or 64 bits, respectively, of the IPv6 address when wireless module 101 sends packets to the Internet 107.

In order to transmit or send data from wireless module 101 to server 105, a wireless module 101 can use module program 101*i* to collect data from a sensor 101*f* in order to update server 105. Module program 101*i* can request a port number 203 from operating system 101*h* in order to have a source IP:port for sending data using IP protocols such as TCP and UDP. The terminology “IP:port” as described herein refers to combining an IP address with a port number. Wireless module IP address 202 and port number 203 can be combined to form IP:port number 204. IP:port number 204 can be utilized as a source IP:port number for packets transmitted from wireless module 101, as well as a destination IP:port number for packets received by wireless module 101, when communicating with server 105.

In order to utilize Internet 107, module 101 may also need a destination IP address and port number in order to send packets to server 105. Before sending data to server 105, wireless module 101 preferably retrieves server IP address 106 and server port number 205 from RAM 101*e*. Server IP address 106 could be recorded in RAM 101*e* via (i) a DNS query using server name 206 or (ii) queries to M2M service provider 108 or wireless network 102. CPU 101*b* may copy server IP address 106 and server port number 205 from nonvolatile memory into volatile memory such as a register for processing to send a packet to server 105. Server name 206 could also be a server identity. (A) Server IP address 106 or server name 206 and (B) server port number 205 could be recorded in a nonvolatile memory such as flash memory 101*w* so that wireless module 101 can store the proper destination of packets transmitted or sent even when wireless module is dormant or shutdown, which avoids the processing and bandwidth requirements of obtaining server IP address 106 and server port number 205 every time the wireless module 101 wakes from the dormant or shutdown state. Server IP address 106 and server port number 205 can be combined into a server IP:port number 207.

After collecting data from a sensor, module 101 can send a packet from IP:port 204 to IP:port 207, and the packet could comprise a message 208 that may include the data from a sensor 101*f*. Note that message 208 does not need to include sensor data, and message could potentially be a periodic registration message or keep-alive message. As contemplated herein, the term “sensor measurement” can refer to data associated with or derived from a sensor 101*f*. A sensor measurement, can comprise a string containing data regarding a parameter of a monitored unit 119 and collected by a sensor 101*f*. The sensor measurement as sent in a message 208 can also represent a string (alphanumeric, binary, text, hexadecimal, etc.), where the string comprises a transformation or processing of sensor data collected by a CPU 101*b*, such including formatting, compressing, or encrypting, encoding, etc. of sensor data.

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In order to minimize bandwidth and time required for RF signals **201** to be active, module **101** can send the message **208** as a single UDP datagram in accordance with a preferred exemplary embodiment. The single UDP datagram in this embodiment can preferably be the only packet sent from module **101** to server **105** or M2M service provider **108** during a wake state for the module **101** when the radio **101z** is active and transmitting, such as in a radio resource control (RRC) connected state. In other words, according to this preferred exemplary embodiment, the message **208** sent by module **101** can preferably be the only message or packet sent by the wireless module to the server **105** between dormant periods of module **101**. By sending message **208** as a single UDP datagram, both a battery **101k** is conserved and utilization of valuable RF spectrum is reduced. Message **208** could also comprise a series of associated UDP messages.

Also, as contemplated herein, message **208** could comprise a related series of packets, so that message **208** could comprise multiple datagrams. As one example, if TCP is utilized as the transport protocol for message **208**, then the series of TCP messages including the initial handshake, one or more packets of payload data, and the closing of the connection could together comprise message **208**. As another example, if UDP or UDP Lite is utilized for the transport protocol, and payload data exceeds a maximum transmission unit (MTU) size for the UDP packet and the payload data is spread across multiple packets, then the multiple packets would comprise a message **208**. Further, a related series of packets comprising a message **208** could be identified by using the same source port number for module **101**. In addition, a related series of packets comprising a first message **208** could be identified as a series of packets sent by module **101** before receiving a response **209** from a server, and packets sent after receiving a response **209** could comprise a second message **208**. Other possibilities for a message **208** to comprise multiple packets or datagrams may exist without departing from the scope of the present invention.

The UDP datagram for message **208** could also be formatted according to the UDP Lite protocol, as specified in IETF RFC 3828, which is also incorporated by reference herein. The term "UDP Lite" described in the present invention may also refer to any connectionless protocol widely supported on Internet **107** where checksums may be partially disabled, thereby supporting the transfer of bit errors within a datagram. The advantages of UDP over TCP is that UDP can be quickly sent, while TCP requires a "handshake" with the server which requires more time and bandwidth, which would utilize more energy from battery **101k**. Weak or "noisy" RF signals between wireless module **101** and wireless network **102** may degrade or slow TCP transmissions, resulting in unwanted and unnecessary retransmission of individual TCP messages in the standard TCP "handshake" and connection close procedures. Also, the sensor data from a sensor **101f** may be relatively small, such as a dozens of bytes in an exemplary embodiment, and UDP can provide significantly less signaling overhead than TCP, especially with small messages for the duration of the session. However, some M2M applications may prefer or require TCP and in this case message **208** can be formatted according to TCP. Thus, according to an exemplary embodiment, both message **208** and response **209** can be TCP messages. In this exemplary embodiment, message **208** and response **209** could each comprise a series of TCP messages that can include a TCP SYN, SYN ACK, ACK, ACK w/data, FIN ACK, etc.

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According to an exemplary embodiment, module **101** sends the same sensor data in multiple copies of the same UDP packet. Each of the multiple copies of the same UDP packet can also optionally be formatted according to the UDP Lite protocol. As one example, wireless module sends three identical copies of the UDP or UDP Lite packet that include the same sensor data. The benefit of sending three copies of UDP Lite include (i) the RF signals **201** received by the base station **103** could include bit errors, which could result in a regular (RFC 768) UDP packet being dropped, since a bit error could result in a UDP checksum mismatch, as received and processed by wireless network **102**. Note that the use of checksums is mandatory in IPv6, and thus checksums cannot be fully disabled in IPv6. With UDP Lite packets transmitted by wireless module **101**, where the mandatory checksum for IPv6 can cover the packet header, wireless network **102** can forward all packets received, potentially including bit errors, to server **105** over the Internet **107**.

Server **105** can receive the multiple copies of the UDP or UDP Lite packets, which could include bit errors received, and server **105** could compare or combine the multiple copies or each individual UDP Lite packet in order to remove bit errors. Note that UDP Lite is not required, and wireless module **101** could send the message **208** using a single UDP packet, or multiple copies of a regular UDP (i.e. non UDP Lite) packet. However, using UDP Lite with multiple packets sent can provide benefits such as if the sensor data is encrypted in the packet, then a single bit error would normally break the receiver's ability to decipher the data using a cryptographic key, unless the encrypted data was channel coded and the channel coding could recover from the bit error in order to present an error-free input of the encrypted data to a deciphering algorithm.

Further, between periods of sleep when a wireless module **101** becomes active and transmits RF signals **201**, module **101**, which may also comprise a wireless module **101i**, could send the sensor data in a single UDP Lite packet where the packet includes channel coding, which can also be referred to forward error correction. Forward error correction could also be implemented by sending multiple copies of the same UDP packet. Note that since large segments of message **208** could include encrypted or hashed data, those segments may not be appropriate for compression since the data is often similar to random strings which are not readily compressed. Channel coding techniques for the data in message **208** could include block codes and convolution codes. Block codes could include Reed-Solomon, Golay, BCH, Hamming, and turbo codes. According to a preferred exemplary embodiment, data within message **208** is sent as a UDP Lite packet using a turbo code to correct multiple bit errors within a packet or datagram sent by module **101** and received by server **105**.

In system **100** illustrated in FIG. 2, server **105** can use IP:port **207** to receive the packet from wireless module **101** and sent from source IP:port **204** to IP:port **207**, and the packet could comprise a message **208** that may include the data from a sensor associated with module **101** or monitored unit **119**. As contemplated herein, a message **208** illustrated in FIG. 2 does not need to include sensor data and other data could be transmitted or sent, such as a server instruction **414** (described in FIG. 4 below), or other data pertaining to module **101** or a monitored unit **119**. Note that server **105** can use IP:port **207** to receive a plurality of messages **208** from a plurality of wireless modules **101**. Server **105** preferably listens for UDP packets on IP:port **207** or monitors IP:port **207**, although TCP packets could be supported as

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well. If server 105 receives multiple copies of the same UDP packet from module 101, server 105 preferably includes a timer. The timer can start when the first packet in the series of packets comprising a message 208 is received, and packets received outside the expiration of the timer would be discarded. In this manner, server 105 would be protected from replay attacks, even though module 101 may send multiple copies of the same packet in order to implement forward error correction. The timer used by a server 105 to drop duplicate packets received outside the timer window could be a relatively short value such as less than 5 seconds.

After receiving the message 208 and processing the message according to the techniques described below such as in FIG. 4, server 105 can send a response 209. Since module 101 may belong to a wireless network 102 which includes a firewall 104, the source IP:port of the message 208 received by server 105 could be different from the source IP:port 204 utilized by wireless module 101. The source IP:port in message 208 could be changed if firewall 104 performs network address translation (NAT), as one example. Server 105 may not readily know if a NAT translation has been performed on the message 208. Alternatively, firewall 104 may not perform NAT, but could still block data from the Internet 107 which does not properly match the firewall rules. As one example, firewall 104 could be a symmetric firewall (but without NAT functionality), where only packets from IP:port 207 to IP:port 204 are allowed to pass the firewall after message 208 has been sent by module 101.

In either case, where firewall 104 may or may not perform NAT routing, server 105 preferably sends the response 209 from the server IP:port 207 to the source IP:port it receives in message 208. According to a preferred exemplary embodiment, response 209 is a UDP packet sent from server 105 with (i) a source IP:port 207 and (ii) a destination IP:port equal to the source IP:port received in message 208, as illustrated in packet 209a. The example use of source and destination IP:ports in message 208 and response 209 are also illustrated in FIG. 6a below. In this manner, the UDP packet can traverse a firewall 104, if firewall 104 is present. If firewall 104 is present and performs NAT routing, then firewall 104 can receive the response 209 and change the destination IP address and port within response 209 to equal IP:port 204.

According to exemplary preferred embodiments, module 101 may also obtain power from a land-line source, such as a traditional 120 volt wall socket, or possibly power over Ethernet, and other non-transient power sources could be utilized as well. In this case, module 101 may remain persistently connected to the Internet through either a wireless network 102 or a wired connection such as Ethernet. In other words, module 101 may omit entering periods of sleep or dormancy where inbound packets from the Internet would not be received due to the sleep state of module 101. Consequently in an exemplary embodiment, module 101 which does not sleep for periods longer than a minute may preferably periodically send a firewall port binding packet 211 from IP:port 204 to IP:port 207 in order to keep ports and addresses within a firewall 104 and/or firewall 124 open to communications between module 101 and server 105. Firewall port binding packet 211 can comprise a packet that is sent periodically using a timer interval that is shorter than the port-binding timeout period 117 on a firewall 104 and firewall 124.

Continuing with this exemplary embodiment where module 101 does not sleep for periods longer than approximately one minute, if UDP is utilized for message 208 and response

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209, then a small UDP packet comprising firewall port binding packet 211 can be sent periodically such as every 45 seconds. If TCP is utilized for message 208 and response 209, then a small TCP packet comprising firewall port binding packet 211 can be sent periodically such as every 4 minutes. Other possibilities for the timing of sending firewall port binding packet 211 are possible as well. By sending firewall port binding packet 211 periodically, server 105 (i) can send module 101 a response 209, which could include a module instruction 502 as explained in FIG. 5a, at (ii) time intervals between message 208 and response 209 that are longer than the firewall port binding timeout values 117 of firewall 104 and/or firewall 124. Without firewall port binding packet 211, if (A) a response 209 sent from server 105 at an exemplary 180 seconds after receiving message 208, such as after a firewall port binding timeout value 117 of firewall 104 of an exemplary 60 seconds, then (B) response 209 would be dropped by firewall 104 and the response 209 would not be received by module 101.

FIG. 3

FIG. 3 is a flow chart illustrating exemplary steps for a server to receive a message from a module, in accordance with exemplary embodiments. As illustrated in FIG. 3, FIG. 3 can include steps used by a module controller 105x in a server 105 as illustrated in FIG. 1c. The processes and operations, including steps for module controller 105x, described below with respect to all of the logic flow diagrams may include the manipulation of signals by a processor and the maintenance of these signals within data structures resident in one or more memory storage devices. For the purposes of this discussion, a process can be generally conceived to be a sequence of computer-executed steps leading to a desired result.

These steps usually require physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, compared, or otherwise manipulated. It is convention for those skilled in the art to refer to representations of these signals as bits, bytes, words, information, elements, symbols, characters, numbers, points, data, entries, objects, images, files, or the like. It should be kept in mind, however, that these and similar terms are associated with appropriate physical quantities for computer operations, and that these terms are merely conventional labels applied to physical quantities that exist within and during operation of the computer.

It should also be understood that manipulations within the computer are often referred to in terms such as listing, creating, adding, calculating, comparing, moving, receiving, determining, configuring, identifying, populating, loading, performing, executing, storing etc. that are often associated with manual operations performed by a human operator. The operations described herein can be machine operations performed in conjunction with various input provided by a human operator or user that interacts with the computer.

In addition, it should be understood that the programs, processes, methods, etc. described herein are not related or limited to any particular computer or apparatus. Rather, various types of general purpose machines may be used with the following process in accordance with the teachings described herein.

The present invention may comprise a computer program or hardware or a combination thereof which embodies the functions described herein and illustrated in the appended flow charts. However, it should be apparent that there could be many different ways of implementing the invention in computer programming or hardware design, and the inven-

tion should not be construed as limited to any one set of computer program instructions.

Further, a skilled programmer would be able to write such a computer program or identify the appropriate hardware circuits to implement the disclosed invention without difficulty based on the flow charts and associated description in the application text, for example. Therefore, disclosure of a particular set of program code instructions or detailed hardware devices is not considered necessary for an adequate understanding of how to make and use the invention. The inventive functionality of the claimed computer implemented processes will be explained in more detail in the following description in conjunction with the remaining Figures illustrating other process flows.

Further, certain steps in the processes or process flow described in all of the logic flow diagrams below must naturally precede others for the present invention to function as described. However, the present invention is not limited to the order of the steps described if such order or sequence does not alter the functionality of the present invention. That is, it is recognized that some steps may be performed before, after, or in parallel other steps without departing from the scope and spirit of the present invention.

The processes, operations, and steps performed by the hardware and software described in this document usually include the manipulation of signals by a CPU or remote server and the maintenance of these signals within data structures resident in one or more of the local or remote memory storage devices. Such data structures impose a physical organization upon the collection of data stored within a memory storage device and represent specific electrical or magnetic elements. These symbolic representations are the means used by those skilled in the art of computer programming and computer construction to most effectively convey teachings and discoveries to others skilled in the art.

At step 311, the server 105 can record a module public key 111, or a plurality of module keys 111 in a module database 105k. The module public key 111 could be received in a message 208 according to steps 516 and 517, including authenticating the message 208, as depicted and described in connection with FIG. 5b below. Module public key 111 could also be recorded at step 311 before module 101 connects to the Internet 107 the very first time, and in this case module public key 111 could be recorded in server 105 by M2M service provider 108 or module provider 109. At step 312, the server 105 can open a TCP/UDP socket associated with an IP:port number 207 and listen or monitor for incoming message from modules. At step 313, server 105 can receive a message 208 sent by module 101, using the IP:port number 207. Although not illustrated in FIG. 3, upon the first communication from module 101 by server 105 where the communication could include step 313, according to an exemplary embodiment, module 101 can also send a certificate 122 to server 105, where certificate 122 would normally include module public key 111 and module identity 110. Server 105 could utilize a certificate 122 to verify a module identity 110, as described in FIG. 4 below at step 412.

An exemplary format of message 208 is depicted and described in connection with FIG. 6a below, and other possibilities for a message 208 exist as well. Although not illustrated in FIG. 3, after receiving message 208, server 105 may also process any channel coding present in message 208 in order to eliminate any bit errors received. The channel coding could be included in a message 208 that utilizes the UDP Lite protocol. At step 314, server 105 can decrypt a

message 208 using a cryptographic algorithm 141 and one of (i) server private key 105c, or (ii) a symmetric key 127. Additional details regarding step 314 are depicted and described in connection with FIG. 4 below. At step 315, server 105 can verify that message 208 was sent by module 101 using a module identity 110, module public key 111, and a cryptographic algorithm 141. Additional details regarding step 315 are depicted and described in connection with FIG. 4 below. Note that step 315 can take place before step 314 if the module identity 110 and/or a digital signature is not encrypted within message 208 (i.e. a sensor measurement in message 208 could be encrypted but a module identity 110 or digital signature may not be encrypted). Step 315 may optionally be omitted, if a symmetric key 127 is used to cipher data within message 208, such that a module digital signature from module 101 was previously verified when the symmetric key 127 was implemented.

After verifying the identity of module 101 in step 315, at step 316 server 105 can record sensor data or sensor measurements within message 208 in a module database 105k, if message 208 has a sensor measurement. Note that message 208 may not have a sensor measurement, and in this case step 316 can be skipped, or message 208 may also include other data besides a sensor measurement. Sensor data recorded in module database 105k can be made available for subsequent processing by server 105 or other servers or applications associated with an M2M service provider 108 in order to manage the function and operation of module 101 or monitored unit 119. As illustrated in FIG. 7 through FIG. 9, received sensor data could also be forwarded by server 105 to an application server 171. Although not illustrated in FIG. 3, in an exemplary embodiment at step 316 server 105 could alternatively forward the sensor data to application 171i instead of recording the data in module database 105k.

After receiving message 208, server 105 can process a response 209 at step 317a. Step 317a can comprise encrypting an instruction, where the instruction could include an acknowledgement of the message received, a command or setting for an actuator, and/or another control message for module 101. Server 105 can utilize a module public key 111 and cryptographic algorithms 141 in order to encrypt the instruction. Step 317b can comprise creating a digital signature for the response 209 using the server private key 105c and cryptographic algorithms 141.

Additional details regarding steps 317a and 317b are depicted and described in connection with FIG. 5a below. Note that step 317a and/or step 317b may optionally be omitted, such that response 209 is transmitted without encryption and/or a signature, and security could be obtained through other means, such as through firewalls 104 and 124, or using a secured network link between module 101 and server 105, such as setting up a virtual private network (VPN) or SSH tunnel between the two endpoints. These alternative means for security at the network layer would likely require additional bandwidth and power consumption for a module 101 and thus may not be adequately efficient. As one example, if module 101 is a wireless module that sleeps for relatively long periods such as every hour (and obtains a new IP address for every wake period), setting up a new VPN between module 101 and server 105 in order to receive send a message from module 101 may not be practical due to the extra drain on a battery 101k for re-establishing the VPN. Or, only portions of steps 317a and 317b could be used, such that a response 209 (or a message 208 received in step 313) is not encrypted but a digital signature is used in the response 209 (or message 208).

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After completing steps 317a and 317b, at step 209a, server 105 can send response 209 from (a) the source port utilized to receive message 208 to (b) a destination IP:port. The destination IP:port can comprise the source IP:port in message 208 as received by server 105, and the destination IP:port can represent the external interface of a firewall 104. In other words, server 105 may send response 209 from server IP:port 207 to the source IP:port received in message 208, which could represent the source IP:port on a wireless network firewall 104, wherein the source IP:port on the wireless network firewall 104 contains the firewall IP address 210. The wireless network firewall 104 could forward the response 209 to module IP:port 204. As contemplated herein, server 105 can send response 209 as soon as practical after receiving message 208, and in any case response 209 should be sent before the expiration of a firewall port binding timeout value 117 associated with firewall 104. According to a preferred exemplary embodiment, response 209 is sent by server 105 within 1 second of receiving message 208. After completing step 209a as illustrated in FIG. 3b, server 105 can return to step 312 and listen for or monitor for additional incoming messages 208 from modules 101.

FIG. 4

FIG. 4 is a flow chart illustrating exemplary steps for a server to process a message, including verifying a module's identity and decrypting data, in accordance with exemplary embodiments. The steps illustrated in FIG. 4 may comprise step 315 and step 316 illustrated in FIG. 3 above. Server 105 can receive message 208 using IP:port 207, as illustrated in FIG. 2. Message 208 can be formatted according to the UDP protocol or UDP Lite protocol, although other possibilities exist as well without departing from the scope of the present invention.

At step 407, server 105 can process the packet using the appropriate transport layer protocol, such as UDP. In this step 407, the body of the packet comprising message 208 can be extracted, and a checksum, if any, can be calculated to verify the integrity. Note that if the UDP Lite protocol is utilized, the checksum may optionally only apply to the packet header. At step 408, server 105 can remove channel coding, if present in message 208. Channel coding techniques utilized in step 408 could include block codes and convolution codes, and can use the same channel coding algorithms used in channel coding algorithms implemented by module 101, depicted and described in connection with FIG. 5a below. By processing channel coding in step 408, server 105 can correct potential bit errors received in message 208, although channel coding 408 may be optionally omitted. As noted above, the use of channel coding 408 can be preferred in an embodiment, since any bit errors received within module encrypted data 403 in message 208 could break (i) a cryptographic algorithms 141 used by server 105 at subsequent steps 413, and/or (ii) the verification of module digital signature 405 at step 410 below.

At step 409, the server 105 can read and record the module identity 110, if module 110 is included in message 208 as external to module encrypted data 403 as illustrated in an exemplary message 208 in FIG. 6a below. Although not illustrated in FIG. 4, server 105 can select a module public key 111 for module 101 by querying a module database 105k with module identity 110. Module identity 110 could comprise a string or session identifier, whereby server 105 could derive or track a module identity 110 from one message 208 to the next message 208 using the string or session identifier. By including module identity 110 in a message 208, but external to module encrypted data 403

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such as illustrated in FIG. 6a below, a server 105 can utilize module identity 110 in order to select a server private key 105c or symmetric key 127 for decrypting module encrypted data 403. According to an exemplary embodiment, a plurality of server private keys 105c could be utilized, where a first private key 105c is used with a first set of modules 101 and a second private key 105c is used with a second set of modules 101. The first and second private keys 105c could use or be associated with different sets of parameters 126. By reading the module identity 110 outside of module encrypted data 403, the module identity 110 can be read before decryption, in order to identify which of the first or second set server private keys 105c that a module 101 sending message 208 is associated with, and thus server 105 can subsequently select the first or second set of server private keys 105c to use when decrypting module encrypted data 403.

Alternatively according to an exemplary embodiment, if server 105 operates in a distributed environment (such as comprising multiple sub-servers 105w as illustrated in FIG. 1f), an unencrypted module identity 110, including a possibly a session identifier for module identity 110 within a message 208, can be utilized by a message preprocessor 105y to select the appropriate sub-server 105w to process the message 208. Server 105 using message preprocessor 105y could forward the message 208 to the correct sub-server 105w. At step 410, server 105 can validate and verify the module identity 110 using the module digital signature 405 inserted by module 101 in message 208. As described in FIG. 4a above, module digital signature 405 can comprise a secure hash signature or tag, where module 101 generated the hash signature using the module private key 112 and digital signature algorithms 141d. As one example, server 105 can utilize the module public key 111 recorded in memory 105e to securely validate the module digital signature 405 receive in a message 208.

The module digital signature 405 can be verified according to public key infrastructure (PKI) standards such as the National Institute of Standards (NIST) "FIPS 186-4: Digital Signature Standard", or IETF RFC 6979 titled "Deterministic Usage of the Digital Signature Algorithm (DSA) and Elliptic Curve Digital Signature Algorithm (ECDSA)". Other PKI standards or proprietary techniques for securely verifying a module digital signature 405 may be utilized as well. If message 208 comprises an initial communication from module 101, at step 412 server 105 can verify that module public key 111 is associated with module identity 110 using a module certificate 122, where certificate 122 includes a signature 123 from a certificate authority 118, as illustrated in FIG. 1h. Server 105 could receive certificate 122 before module 101 sends message 208, or server 105 could query module 101 or another server for certificate 122 after receiving message 208. Server 105 could use digital signature algorithms 141d to compare a secure hash calculated using (i) a first certificate 122 and/or public key from module 101 and (ii) a second certificate and/or public key from certificate authority 118 or another server, in order to confirm that module public key 111 is associated with module identity 110, where module identity 110 was read from message 208 in step 409. The secure hash could also be calculated using module public key 111 and a public key from certificate authority 118, and other possibilities using PKI exist as well for server 105 to confirm module public key 111 is associated with module identity 110 at step 412.

Steps 409 and 410 are not required to utilize the efficient techniques described herein, and may optionally be omitted. As one example, security could be maintained at the network

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layer through the use of wireless network firewall 104 and server network firewall 124, such that only an inbound message 208 to server 105 could be received by server 105 after security methods are applied at the network layer or application layer. Note that if (A) module encrypted data 403 includes module identity 110 and/or module digital signature 405, then (B) steps 409 and/or 410 may also take place after step 413, where server 105 (i) first decrypts module encrypted data 403 and can then (ii) verify module identity 110 by performing steps 409 and 410 after step 413. If module encrypted data 403 utilizes a symmetric cipher 141b, then a module identity 110 can preferably be external to module encrypted data 403 so that server 105 can select the appropriate symmetric key 127 used by module 101 in order to decipher module encrypted data 403 (since a plurality of modules 101 may communicate with server 105 concurrently).

After verifying module digital signature 405 in step 410, server 105 can record an authenticated module encrypted data 403 from module 101 received in message 208. At step 413, server 105 can decrypt module encrypted data 403 using cryptographic algorithms 141 and either (i) server private key 105c as a decryption key with asymmetric ciphering 141a or (ii) symmetric key 127 with symmetric ciphering 141b. A symmetric key 127 may be stored in a module database 105k, as noted in FIG. 1f above. If a symmetric key 127 is used at step 413, the symmetric key 127 could be (i) sent by server 105 in a response 209 or (ii) received by server 105 in a prior message 208, before the message 208 illustrated in FIG. 4 was received by server 105.

With an asymmetric ciphering 141a scheme used in a module encrypted data 403 and by cryptographic algorithms 141 at step 413, server 105 can decrypt module encrypted data 403 using (i) server private key 105c and (ii) RSA algorithms 153, elliptic curve cryptography (ECC) algorithms 154, or other algorithms for public key cryptography. The use and application of RSA algorithms 153 and cryptography are described within IETF RFC 3447, among other published standards. The use and application of ECC cryptography and algorithms are described within IETF RFC 6637, among other published standards. ECC algorithms 154 may be preferred in order to maintain high security with small key lengths, compared to RSA, in order to minimize the message lengths, radio frequency spectrum utilization, and processing power required by module 101. Thus, the use of ECC algorithms within a decryption algorithm at step 413 may help conserve the life of a battery 101k of module 101 while maintaining the objective of securing system 100. Note that module encrypted data 403 may also include a security token 401 (not shown in FIG. 4, but shown in FIG. 5a), which could comprise a random string, and thus each module encrypted data 403 received by server 105 in message 208 may be reasonably considered unique and thus robust against replay attacks.

With a symmetric ciphering 141b scheme used in a module encrypted data 403 and by cryptographic algorithms 141 at step 413, server 105 can decrypt module encrypted data 403 using (i) symmetric key 127 and (ii) a symmetric cipher 141b such as AES 155, Triple DES, or similar secure symmetric ciphers. As one example, by using ECC cryptography and ECIES, server 105 could decrypt module encrypted data at step 413 by using the steps outlined in FIG. 3, titled "ECIES Encryption Functional Diagram" in "A Survey of the Elliptic Curve Integrated Encryption Scheme" by Martinez et al in the Journal of Computer Science and Engineering, Volume 2, August 2010, page 11, (herein

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incorporated by reference). Other possibilities exist as well without departing from the scope of the present invention. Server 105 can utilize step 413 illustrated in FIG. 4 to extract the plaintext, or decrypted data within module encrypted data 403.

After decrypting module encrypted data 403, server 105 can read the resulting data within message 208, which could comprise a server instruction 414. The server instruction 414 can represent the purpose of the message 208 for server 105. Server instruction 414 could comprise a plurality of different procedures for server 105, such as an "update" with sensor data, a "query" for data or instructions from server 105 or M2M service provide 108, a "notification" of state or condition at module 101 such as an alarm or error, a "configuration request" where module 101 seeks configuration parameters, a "software request" where module 101 request updated software or routines, a "registration" message where module 101 periodically registers with server 105, etc. Thus, server instruction 414 can comprise the purpose module 101 sends message 208. In addition, server instruction 414 could comprise a "confirmation", where module 101 sends a "confirmation" in a second message 208 after receipt of a response 209, where response 209 could include a module instruction 502 (below), and the "confirmation" in this second message 208 could signal server 105 that the module instruction 502 had been properly executed. As contemplated herein, the term "Message (update)" can comprise a message 208 that includes a server instruction 414 of "update", and the term "Message (confirmation)" can comprise a message 208 that includes a server instruction 414 of "confirmation", etc.

As examples for server instruction 414, an "update" could be used to periodically notify server 105 of regular, periodic sensor data 305 acquired by a sensor 101f. An "update" for server instruction 414 may also comprise a periodic report regarding monitored unit 119 or information regarding a state, condition, or level for an actuator 101y. A "query" for server instruction 414 could comprise module 101 querying server 105 for data from a module database 105k, where the data could be associated with monitored unit 119, wireless network 102, an element within module 101 such as an actuator setting. A "notification" for server instruction 414 could comprise module 101 notifying server 105 that an alarm or error condition has occurred, such as a sensor measurement exceeds a threshold value or another error condition such as loss of contact with monitored unit 119. A "configuration request" for server instruction 414 could comprise module 101 requesting server 105 for configuration parameters or a configuration file. Other possibilities for server instruction 414 exist without departing from the scope of the present invention.

At step 415, server 105 can process the server instruction 414. If server instruction 414 comprises an "update", then sensor data, or other data in server instruction 414 including potentially a new symmetric key 127 generated by module 101, could be recorded in module database 105k. Other applications may subsequently access the sensor data for generating reports or making decisions regarding monitored unit 119. If server instruction 414 comprises a "query", then server 105 could execute the query at step 415. If server instruction 414 comprises a "notification" of an alarm, then step 415 could initiate procedures for alarm notification to 3rd parties or alarm resolution. Other possibilities for processing a server instruction 414 at step 415 exist without departing from the scope of the present invention.

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FIG. 5a

FIG. 5a is a flow chart illustrating exemplary steps for a server to process a response for a module, including sending and signing a module instruction, in accordance with exemplary embodiments. The steps illustrated in FIG. 5a may comprise step 317a and step 317b illustrated in FIG. 3 above. Since message 208 and response 209 may traverse the public Internet 107, a module 101 and a server 105 may prefer to take additional steps to sending plaintext in packets in order to maintain security of a system 100. Server 105 can process a response 209 to a message 208 from module 101 using a module public key 111 and a server private key 105c, according to a preferred exemplary embodiment. If a symmetric cipher 141b is utilized within cryptographic algorithms 141, then server 105 may also utilize a symmetric key 127 to encrypt data within a response 209. Note that the security methods described herein are optional, and message 208 and response 208 can be sent without any or all of the additional security steps described herein, but the use of these security steps may be preferred.

After receiving message 208 as illustrated in FIG. 2, server 105 can prepare an acknowledgement 501. The acknowledgement 501 can be a simple text, binary, or hexadecimal string to confirm that message 208 has been received and/or processed by server 105. Since message 208 may be transmitted via a UDP or UDP Lite packet, module 101 may preferably utilize a reply message from server 105 containing acknowledgement 501, in order to confirm message 208 has been received by server 105. Alternatively, if TCP is used to transmit message 208, an acknowledgement 501 may be used at the application layer of the Open Systems Interconnection (OSI) model, wherein a simple TCP ACK message may operate at the lower transport layer than the application layer. UDP may be preferred over TCP in order to reduce processing resources for module 101 and server 105, especially considering the relatively small and comparably infrequent messages sent between a module 101 and a server 105 (when compared to web browsing and considering module 101 may have a battery 101k that may preferably last for weeks or longer without recharging). In processing a response 209, server 105 may optionally add a security token 401, which could be a random number 128a, or a randomly generated text, binary, or hexadecimal string. Security token 401 could be a random number 128a or string that is included in response 209 in order to make each response 209 unique and thus avoid any replay attacks when response 209 traverses Internet 107. Note that a message 208 may also preferably include a security token 401.

In other words, the use of security token 401 can ensure to a high level of certainty that each response 209 will be different and thus the data within response 209 would not be sent more than once. Note that security token 401 may be generated by module 101 in message 208, and in this case server 105 can use the same security token received in message 208. Security token 401 can alternatively be generated by server 105 and different than any security token 401 received in message 208. As one example, server 105 could use a first security token 401 received in message 208 to process a second security token 401, where the second security token 401 is generated using (i) a pre-agreed algorithm between module 101 and server 105 and (ii) the first security token 401 as input into the pre-agreed algorithm. Security token 401 illustrated in FIG. 5a can be derived or processed by using message 208 in accordance with preferred exemplary embodiments.

Server 105 may also optionally add a module instruction 502 when preparing a response 209. The module instruction

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502 could be a string that contains instructions or configuration parameters for module 101, such as an order to change state, parameters regarding the monitoring of monitored unit 119, server names or addresses, radio frequency parameters, wireless network 102 authentication parameters or keys, keys for communication with server 105 or M2M service provider 108, etc. Module instruction 502 may also comprise an instruction to change the state of actuator 101y, a timer value, a sensor threshold value, the threshold for an alarm state, and information for display at a user interface 101j, an instruction to sleep, etc. Module instruction 502 may further comprise an updated module private key 112, and updated server public key 114, or the address or name of a new server 105 added to M2M service provider 108. According to an exemplary preferred embodiment, a module instruction 502 could comprise a "key generation" instruction, where module 101 generates a new pair of a module private key 112 and a module public key 111, utilizing the exemplary steps and procedures illustrated in FIG. 5b below. The "key generation" 608 module instruction 502 (illustrated in FIG. 6a below) could be used to create new keys for a new purpose (such as connecting to a new wireless network 102 or communicating with a new server 105), while the existing keys used to communicate with server 105 could remain operable or be deprecated at a later time. Alternatively, an existing module public key 111 could be deprecated or become invalid once server 105 sends a "key generation" module instruction 502.

In order to control module 101, server 105 would normally need to include module instruction 502 in the response 209 only after receiving message 208, since the server 105 would normally not be able to send messages to a module 101 at arbitrary times, such as before a message 208 has been received by the server 105. The reasons include (i) the module may normally be in a sleep or dormant state, in order to conserve battery life or power consumption, where an unsolicited incoming Internet packet from server 105 would not be received by module 101, and (ii) a wireless network 102 (or equivalent wired network that a wired module 101 could connect with) may frequently include a firewall 104. Firewall 104 could prevent packets from the Internet 107 from reaching module 101 unless module 101 had previously first sent a packet to server 105 within a firewall port-binding timeout period 117 of firewall 104. The port-binding timeout period of a firewall 104 may be an exemplary period such as 20-60 seconds for UDP packets and several minutes for TCP packets. Note that module instruction 502 may optionally be omitted, such that (b) some response 209 messages may include module instruction 502, and (b) other response 209 messages may omit module instruction 502, but include an acknowledgement 501 to message 208. Also note that according to an exemplary embodiment described herein, the use of optional strings or steps can be depicted in FIGS. 4 and 5a through the use of dashed lines for the various elements illustrated.

Server 105 may then use as input the acknowledgement 501, security token 401, and module instruction 502, including optional data and parameters 126, into cryptographic algorithms 141 at step 503. The cryptographic algorithms 141 at step 503 can utilize either (i) module public key 111 as an encryption key if asymmetric ciphering 141a is utilized, or (ii) a shared symmetric key 127 if a symmetric cipher 141b is utilized, such as AES 155 ciphering. The output of cryptographic algorithms 141 at step 503, using acknowledgement 501, security token 401, and module instruction 502, plus optional data and parameters 126, as input, can be server encrypted data 504, as illustrated in FIG.

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5a. Server encrypted data 504 could be a string or number, including a text, binary, or hexadecimal string or series of numbers or bits, and other possibilities for the format of server encrypted data 504 exist as well, including a file, without departing from the scope of the present invention. By using module public key 111 and/or symmetric key 127 in the cryptographic algorithms 141 at step 503, server encrypted data 504 may only be reasonably decrypted by module 101 using module private key 112 and/or symmetric key 127. Thus the response 209 transmitted across an Internet 107 may be reasonably considered secure and only reasonably decrypted by module 101.

Server 105 can then process server encrypted data 504 by appending or including server identity 206. Note that server identity 206 can be appended or included after the operation of step 503, since the server identity 206 may optionally be openly readable within a response 209 transmitted or sent to module 101. As one example, server identity 206 could comprise IP address 106 as a source IP address in response 209, which would be openly readable on the Internet 107 since a valid packet must have a source and destination IP address. Additional details on an exemplary structure of response 209 are illustrated in FIG. 6a below. By including server identity 206 after encryption at step 503, the module can read the server identity 206 and verify a digital signature within response 209 without having to first decrypt data within response 209 using the module private key 112 or symmetric key 127. Note that server identity 206 could alternatively be included within server encrypted data 504, such that step 505 takes place before step 504. In other words, including server identity 206 external to a server encrypted data 504 can be used by module 101 to select the proper server public key 114 when verifying a digital signature in response 209.

Server 105 can then process a server digital signature 506 using the server private key 105c. The server digital signature 506 can be processed according to public key infrastructure (PKI) standards such as the National Institute of Standards (NIST) "FIPS 186-4: Digital Signature Standard" (which is hereby incorporated herein by reference), or IETF RFC 6979 titled "Deterministic Usage of the Digital Signature Algorithm (DSA) and Elliptic Curve Digital Signature Algorithm (ECDSA)" (which is hereby incorporated herein by reference). The use of a server digital signature 506 can be processed according to the description of a digital signature according to the Wikipedia entry for "Digital Signature" as of Sep. 9, 2013, which is incorporated by reference herein in its entirety. Also note that other uses of a digital signature as contemplated within the present invention may refer to the above three references and related standard techniques for processing and creating digital signatures. Other PKI standards or proprietary methods for securely generating a server digital signature 506 may be utilized as well.

According to a preferred exemplary embodiment, ECC algorithms for generating server digital signature 506 may be utilized in order to minimize the key length compared to RSA algorithms. Server digital signature 506 may comprise a secure hash signature using a hash algorithm such as secure hash algorithm 1 (SHA-1), or subsequent standards such as SHA-2 and SHA-3, and other possibilities exist as well. Server digital signature 506 is illustrated in FIG. 5a as being processed after server encrypted data 504, but server digital signature 506 may also optionally be included in server encrypted data 504. Step 506 may also take place before step 505.

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Also note that server digital signature 506 may preferably be included in a response 209 before module 101 begins either (i) utilizing a symmetric key 127 shown in step 413 to encrypt a module encrypted data 403, or (ii) accept or process a module instruction 502. After including server digital signature 506 in a first response 209 that uses asymmetric ciphering 141a, server 105 may omit server digital signature 506 in a second subsequent response. The second subsequent response could be a case where (i) server encrypted data 504 utilizes a symmetric key 127 for ciphering (where server 105 received the symmetric key 127 in a message 208 that utilized asymmetric ciphering 141a as illustrated in FIG. 4 above) and (ii) expiration time 133 of symmetric key 127 has not transpired.

Although energy may be conserved for a module 101 utilizing the exemplary steps illustrated in FIG. 5a and elsewhere herein, a high level of security is desirable for many "machine-to-machine" applications. A module 101 may be utilized for industrial applications or health monitoring, where the receipt of unauthorized module instructions 502 from 3rd parties could result in damages or losses. Without proper security that can include the steps illustrated in FIG. 5a, response 209 could include a module instruction 502, and module 101 could potentially receive commands or instructions from sources other than server 105, such as hackers.

FIG. 5b

FIG. 5b is a flow chart illustrating exemplary steps for a server to communicate with a module that has derived a public key and private key, in accordance with exemplary embodiments. In order to utilize communications secured with PKI techniques such as private keys, public keys, certificates, and identities, a module 101 may preferably obtain or generate these keys and utilize a module identity 110 and/or a certificate 122 in a secure manner. Given that a plurality of modules 101 may be deployed in potentially remote places, without frequent contact with end users or technicians, the use of secure PKI techniques for a module 101 can create a significant set of challenges for the generation of module public key 111 and module private key 112, as well as properly and securely obtaining a certificate 122 with an module identity 110. Using conventional technology, significant challenges and costs can be incurred when (i) module 101 has already been deployed, such as collecting data from a monitored unit 119, and (ii) module 101 needs to utilize a new set of module private key 112 and module public key 111.

Exemplary embodiments that include derivation or processing of a new module private key 112 and module public key 111 may utilize the particular steps and procedures contemplated herein, in order to minimize any potential human intervention (with related costs) while continuing to maintain or also enhance security, compared either (i) externally generating module private key 112, and/or (ii) continuing to use the same module private key 112 for the lifetime of module 101. Over a long period of operating time for a module 101, such as several years or longer, there may be many reasons module 101 may need a new pair of PKI keys, such as (i) expiration of a certificate 122, or the certificate 122 of a parent signature authority, (ii) the transfer of ownership or control of module 101, where the prior ownership could have direct or indirect access to the module private key 112, (iii) supporting a new server 105 that has different security requirements or a different set of parameters 126 (longer keys, different ECC curves, different cryptographic algorithms 141, etc.), and/or (iv) revocation of a public key in a chain of signatures 123 associated with

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a certificate 122. In the case of (ii) above, new ownership of module 101 may require a module 101 to utilize a new module private key 112 since the old ownership may have access to an old module private key 122. In the case of (iii) above, a new server 105 may require a pair of public/private keys incompatible with a prior set of public/private keys utilized by module 101 and/or a certificate 122 for module 101.

Other possibilities exist as well for reasons why a module 101 and/or server 105 may prefer for a module 101 to utilize a new module public key 111 and new module private key 112. In an exemplary embodiment, module 101 may generate a new public/private key periodically in order to enhance the security of a system 100. A benefit of a system 100 supporting periodic generation of keys by module 101 is that the key length can be shortened in order to obtain a similar level of security, and the processing power and energy consumption, possibly from a battery 105k, can be reduced through the use of shorter key lengths. In other words, over time such as several months or years, the use of a plurality of different pairs of public/private keys for module 101 with shorter key lengths can be both more secure and energy efficient than using a single pair of public/private keys with a longer key length for the lifetime of module 101. Shorter key lengths may also be more compatible with processing power constraints of a module 101. Thus, in exemplary embodiments, module 101 and/or server 105 may prefer for module 101 to periodically generate new public and private keys.

The general approach adopted by most mobile phone networks over the past two decades has been founded upon the use of a pre-shared secret key recorded in SIM cards, such as the Ki pre-shared secret key in 2G and 3G networks. That approach may work for mobile phones, where the SIMs can often be easily replaced, but the use of a pre-shared secret key in a SIM may not be suitable for a module 101 and M2M service provider 108 for many circumstances. As one example, significant costs may be incurred by swapping out a SIM card for already deployed modules 101, especially if they are in remote locations or continually moving such as a tracking device on a container, pallet, truck, or automobile. In an exemplary embodiment, a module 101 may preferably record multiple pairs of public/private keys 111/112 for various and different functions, such as connecting to different servers 105, connecting to different wireless networks 102, etc. As contemplated herein, recording more than one public/private key 111/112 can comprise module 101 recording a plurality of pairs of module public keys 111 and module private keys 112. In exemplary embodiments, one pair comprising a first module public key 111 and a first module private key 112 can be identified or selected from a different pair comprising a second module public key 111 and a second module private key 112 using a module public key identity 111a.

The number of pairs of public/private keys useful to a module 101 concurrently could be several, such as an exemplary three or more actively used public/private keys, although other possibilities exist as well. Manually trying to change or add a new SIM card each time a new security key is required may not be efficient or feasible. Or in another exemplary embodiment, the multiple pairs of private and public keys could be used in sequence, such that module 101 with server 105 utilizes a single module public key 111 and module private key 112 at any given point in time. In the case where module 101 (i) uses more than one private key 112 and more than one public key 111 and (ii) derives at least one module private key 112 and one public key 111 during

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the lifetime of module 101, this case may be considered module 101 using a plurality of module private keys 112 and using a plurality of module public keys 111. In the case where module 101 derives or generates more than one module private key 112 and module public key 111 during the lifetime of module 101, this case may be considered module 101 deriving a plurality of module private keys 112 and module public keys 111, or also deriving a plurality of pairs of module public keys 111 and module private keys 112. The various pairs in the plurality may use different sets of parameters 126 or the same set of parameters 126. The plurality of module public keys 111 and module private keys 112 can be processed by a CPU 101b with key pair generation algorithms 141e and a random number generator 128. The random number generator 128 can use input from a sensor 101f, a radio 101z, and/or temporary random seed file.

In exemplary embodiments, module 101 can use a module public key 111 for sending a module encrypted data 403 or receiving a server encrypted data 504 by either (i) sending the module public key 111 to a server 105 in order to allow the module encrypted data 403 to be decrypted (such as using a step 413) or the server encrypted data 504 to be encrypted (such as using a step 503), or (ii) inputting the module public key 111 into a key derivation function 141f in order to derive or process a derived shared secret key 129b, which could be used with a symmetric key 127. Other possibilities exist as well for module 101 to use its own public key 111 with cryptographic algorithms for communicating with a server 105.

FIG. 5b illustrates exemplary steps that can be performed with module 101, including using a module program 101i, for generating, deriving, and/or updating a module public key 111 and module private key 112. The steps illustrated in FIG. 5b include both (i) an "initial" or "startup" case where module 101 has not previously derived keys (or keys not internally derived may not have been loaded), and (ii) a subsequent or "follow on" time where module 101 can generate or derive keys after keys were initially obtained or derived. Note that efficient and secure methods and systems contemplated herein, including in FIG. 5b, may also be utilized with a regular consumer mobile phone, or smart-phone, as a module 101. Mobile phones as module 101 can benefit from (i) deriving a module public key 111 and a module private key 112, (ii) sending module encrypted data 403 in a message 208 using the derived keys, and (iii) receiving a server encrypted data 504 in a response 209 also using the derived keys. In the exemplary embodiment where module 101 comprises a mobile phone, then sensor 101f may comprise a microphone and actuator 101y may comprise a speaker, and other possibilities exist as well to those of ordinary skill in the art for module 101 to comprise a mobile phone.

At step 511, during manufacturing of module 101, including manufacturing of subcomponents such as a circuit board, assembly of hardware components illustrated in FIG. 1b, etc., a module identity 110 could be written into the hardware, and could comprise a serial number, International Mobile Equipment Identity (EVEI) number, Ethernet MAC address, or a similar persistent identification for a module 101. An IEMI number may be used with a mobile phone as module 101, in a preferred embodiment. For security purposes, the module identity 110 may preferably be written into a read-only location, such as a readable location on a system bus 101d, which could also comprise a ROM 101c. Recording and utilizing module identity 110 is also depicted and described in connection with FIG. 1e, FIG. 2, and

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elsewhere herein. Alternatively, module identity 110 could be recorded in a non-volatile memory such as a flash memory 101w.

At step 512, module 101 can be distributed to end users and also installed with a monitored unit 119. If module 101 is a mobile phone, then monitored unit 119 could be a person that carries the mobile phone. Also note that a monitored unit 119 could be omitted, and a module 101 could use the techniques contemplated herein. At step 513, a shared secret key 510, parameters 126, and a server address 207 can be recorded in a nonvolatile memory 101w. Parameters 126 may comprise settings for a cryptographic algorithms 141 as illustrated in FIG. 1g, including (i) key lengths, (ii) algorithms to utilize for key generation or ciphering, such as selecting RSA algorithms 153 or ECC algorithms 154, (iii) a specific secure hash algorithm 141c to utilize, such as SHA-256 or SHA-3, (iv) an expiration date of the module public key 111, (v) a maximum time value for an expiration time 133 associated with a symmetric key 127, (vi) a ECC parameters 137 or an ECC standard curve 138 as parameters 126 in FIG. 1h, (vii) the specification of or values for a padding scheme for use with a digital signature algorithms 141d, and/or similar or related values for using cryptographic algorithms 141d. Although not illustrated in FIG. 5b, at step 512 a configuration file could also be loaded into non-volatile memory, where the configuration file includes a plurality of fields specifying the operation of module 101. The shared secret key 510, parameters 126, and server address 207 could be included in a configuration file.

Continuing at step 513, server identity 206 could be utilized in place of or in addition to server address 207, and in this case module 101 can later perform a DNS or DNSSEC lookup using server identity 206 in order to obtain server address 207 for use in a message 208, such as the destination address. Shared secret key 510 and server address 207 (or server identity 206) could also be recorded in a ROM 101c at step 513. Step 513 may also be performed concurrently with step 511 or step 512. According to an exemplary embodiment, a manufacturer may perform step 513 and in this case step 513 could take place concurrently with step 511. In another embodiment, a distributor of module 101 could perform step 513 and in this case step 513 could take place concurrently with step 512. Alternatively, step 513 may be performed by a technician or end user after manufacturing and distribution and before module 101 begins collecting sensor data with a monitored unit. Other possibilities exist as well for the sequence of steps 511 through 513 illustrated in FIG. 5b without departing from the scope of the present invention.

Note that step 513 may take place multiple times during the lifetime of a module 101, and in this case (a) the first time step 513 is conducted, step 513 could be conducted concurrent with steps 511 or 512, and (b) a subsequent time step 513 is conducted, step 513 could be conducted after the receipt of a response 209, where the response 209 includes a second shared secret key 510, server address 207, and also potentially a new module identity 110. In other words, although not illustrated in FIG. 5b, a module 101 could return to step 513 from later steps upon the equivalent of a "factory reset", or similar command where flash memory 101w and other nonvolatile memory would be cleared. In an exemplary embodiment where step 513 takes place a second time may potentially be the transfer of ownership or control of module 101, or a another embodiment where step 513 takes place a second time could be the upload of new firmware that is incompatible with a previous configuration file. In any case, shared secret key 510 can preferably be

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uniquely associated with module 101 (i.e. any given shared secret key 510 may belong only to an individual module 101).

Shared secret key 510 may comprise a pre-shared secret key 129a, as described in FIG. 1e. If module 101 has already derived a module private key 112 and module public key 111 (such as when step 513 is being conducted at a second or additional time as contemplated in the previous paragraph), then shared secret key 510 may comprise (i) a key received in a server encrypted data 504 including possibly a symmetric key 127, or (ii) a derived shared secret key 129b. Derived shared secret key 129b could be obtained from using a key derivation function 141f and module public key 111 and server public key 114, using a module public key 111 that has already been derived or used by module 101 (such as if at least one module private key 112 and module public key 111 had already been used or derived before step 513).

As contemplated herein in an exemplary embodiment, an first module private key 112 and first module public key 111 could be derived outside module 101 and loaded into a nonvolatile memory such as flash memory 101w at a prior time before step 513, and the shared secret key 510 could be received by module 101 using the first module private key 112 and module public key 111 (such as receiving the shared secret key 510 in a server encrypted data 504 using the first module private key 112 which had been loaded). Step 513 could then comprise a later time after the server encrypted data 504 has been received that includes the shared secret key 510, where module 101 may (i) prefer to begin utilizing keys that module 101 internally derives using cryptographic algorithms 141 instead of (ii) continuing to use the first module public key 111 and module private key 112 that were derived outside of the module 101, such as possibly loaded into a nonvolatile memory from an external source.

In the embodiment where shared secret key 510 has not been received by module 101 in a server encrypted data 504, shared secret key 510 could be obtained and loaded by a distributor, installer, or end user into a nonvolatile memory such as flash memory 101w in the form of a pre-shared secret key 129a, where pre-shared secret key 129a was obtained using a module identity 110 and pre-shared secret key code 134 as depicted and described in connection with FIG. 1e above. Module 101 could also utilize a first pre-shared secret key 129a, including a first pre-shared secret key 129a entered by potentially a distributor, installer, or end-user described in FIG. 1e, to derive shared secret key 510. Other possibilities exist as well for shared secret key 510, and shared secret key 510 can be useful for the proper identification and/or authentication of module 101 upon module 101's generation of a private key 112 and public key 111, as described below including step 517. If module 101 is a mobile phone, as contemplated herein, shared secret key 510 could be loaded by a distributor or company selling or servicing the mobile phone, or shared secret key 510 could be obtained by the end user or subscriber accessing a web page associated with a mobile operator for a wireless network 102 associated with the mobile phone and/or SIM card.

Also note that as contemplated herein, an initial module private key 112 and initial module public key 111 could be recorded into nonvolatile memory at step 513. For example, a manufacturer, distributor, installer, technician, or end-user could load the initial module private key and initial module public key 111, where the initial module public key 111 would be utilized to authenticate at step 517 a subsequent set of public/private keys derived by module 101 at step 515. In

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this case, the initial module public key **111** and/or initial module private key **112** described in the previous two sentences could comprise the shared secret key **510**. One reason the initial module private key **112** with the initial module public key **111** would comprise a shared secret key **510** may be that (i) the initial module private key **112** and initial module public key **111** together have been “shared” in the sense that the initial module private key **112** has been located outside module **101** and in possession of an entity such as the manufacturer, distributor, installer, technician, or end-user in order to load the initial module private key into a nonvolatile memory such as flash memory **101w** (and initial module public key **111** is subsequently shared with server **105**), (ii) the initial module private key **112** and initial module public key **111** can be used to authenticate a subsequent message **208** containing a public key internally derived by the module at step **517** below, and (iii) the initial module private key **112** would remain “secret” in the sense that it is not publicly shared (i.e. an initial or “loaded” module private key **112** could preferably be kept confidential and thus part of a “shared secret key”). Thus, FIG. **5b** also contemplates an embodiment where shared secret key **510** at step **513** comprises an initial public/private key pair for module **101** that is not internally derived by module **101**, including keys derived at step **515**.

Note that the contemplation of the use of shared secret key **510** as a pre-shared secret key **129a** within the present invention may be different than the use of a pre-shared secret key within a SIM card as commonly supported by wireless networks **102** with mobile phones in 2013. Specifically, as depicted and described in connection with FIG. **1e** and elsewhere herein, the shared secret key **510**, either (i) comprising a pre-shared secret key **129a** or (ii) derived from a pre-shared secret key **129a**, may be moved by CPU **101b** into a volatile memory such as RAM **101e**, with subsequent access by cryptographic algorithms **141**. In contrast, the pre-shared secret key within a SIM card for mobile phones is usually designed to prevent movement of the pre-shared secret key within a SIM into RAM **101e**.

If a SIM card is present within module **101**, and the SIM card contains a pre-shared secret key, such as **Ki**, then as contemplated herein, shared secret key **510** may be derived using the SIM card and **Ki**. As one example, module **101** could (i) utilize a RAND message, potentially received from a 3G or 4G mobile network such as wireless network **102**, and (ii) input the RAND into the SIM card and receive a response RES (or SRES), and utilize the string in RES to process or derive a shared secret key **510**. Response RES could also comprise a shared secret key **510**. Server **105** could also submit the same RAND associated with the SIM card and **Ki** to wireless network **102**, and receive the same RES as obtained by module **101**. By both module **101** and server **105** having the same RES value, they can follow a pre-agreed series of steps to use the same RES in order to derive a commonly shared secret key **510** (or the shared RES could comprise a shared secret key **510**). In one embodiment where module **101** includes a SIM card for a wireless network **102**, such as a 4G LTE network, module **101** and server **105** could both utilize a key derivation function **141f**, using the same RES as input, in order to derive the same shared secret key **510**.

At step **514**, module **101** can read module identity **110** using a read-only address. Module **101** can read module identity **110** directly from read-only hardware address by using system bus **101d**, including from a ROM **101c**, or module **101** can read module identity **110** from a nonvolatile memory such as a flash memory **101w**. Thus, the read-only

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address could comprise an address accessible on system bus **101d** that is designated read-only for a period of time. The module identity **110** could be recorded into a flash memory **101w** by module **110** after a prior read of module identity **110** from a read-only address. In this case (module **101** taking the step described in the previous sentence), reading module identity **110** from the nonvolatile memory at step **514** can also comprise module **101** reading module identity **110** using a read-only address. Thus, although module **101** may read module identity **110** from a flash memory **101w**, if (a) module **101** initially utilized a read-only address to record the module identity **110** into the flash memory **101w**, then (b) reading module identity **110** from the flash memory **101w** could comprise using a read-only address to read module identity **110**. Other possibilities exist as well, such as the address that includes module identity **110** in either (i) a nonvolatile memory such as a ROM **101c** or (ii) an address accessible on system bus **101d**, could be designated for a period of time as available for a read-only operation. Step **514** could also take place after step **515** below.

At Step **515**, module **101** can derive module private key **112** and a corresponding module public key **111** using (i) random number generator **128**, (ii) parameters **126**, (iii) cryptographic algorithms **141**, and/or (iv) a key pair generation algorithm **141e**. Module **101** at step **515** and elsewhere in the present invention can be a mobile phone such as a smartphone. Private key **112** and corresponding module public key **111** can be derived according to a wide range of parameters **126**, and can utilize different algorithms for different pairs of keys, such as RSA **153** or ECC **154**. Key derivation at step **515** could generate keys of various lengths, such as 2048 bits with RSA **153** or 283 bits with ECC **154**, and other possibilities exist as well. If using ECC **154** to derive a pair of keys for module **101**, step **515** could also accommodate the use of different elliptic curves for compatibility with server **105**, such as the use of odd-characteristic curves, Koblitz curves, and making sure the derived keys by module **101** use a compatible or identical elliptic curve or defined elliptic curve equation as server **105**, etc. Module **101** can use ECC parameters **137** or an ECC standard curve **138** in a parameters **126** to derive module private key **112** and/or module public key **111**.

Deriving keys in step **515** could also comprise using values such as constants or variables in a parameters **126** to define an elliptic curve equation for use with an ECC algorithm **154**. The values or constants to define an equation for an elliptic curve could be input into a key pair generation algorithms **141e** in the form of ECC parameters **137** or an ECC standard curve **138**. In an exemplary embodiment, where a parameters **126** does not include constants and variables for defining an elliptic curve equation, a key pair generation algorithms **141e** could use pre-defined elliptic curves with ECC algorithms **154** such as standardized, named curves in ECC standard curve **138** including exemplary values such as sect283k1, sect283r1, sect409k1, sect409r1, etc. Exemplary, standardized named curves, as opposed to module **101** and server **105** using an internally generated elliptic curve equation using parameters **126**, are also identified as example curves in IETF RFC 5480, titled “Elliptic Curve Cryptography Subject Public Key Information”. Thus, module **101** could use either standardized elliptic curves, or a separate defined elliptic curve equation as specified in a parameters **126**.

The curve for module **101** to utilize in deriving module public key **111** and module private key **112** at step **515** could be specified in parameters **126**. Consequently, the parameters of keys generated by module **101** at step **515** (including

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key length or algorithms utilized) may be selected based upon the requirements of the application and can be included in a parameters 126. When deriving keys at step 515, module 101 may also preferably utilize data from sensor 101f, radio 101z, a bus 101d, a physical interface 101a, memory 101e, and/or a clock in order to generate a seed 129 for random number generator 128, or random number generator 128 could utilize these inputs directly. A random number 128a can be input into key pair generation algorithm 141e in order to derive the module public key 111 and module private key 112. Note that with ECC algorithms 154, a module private key 112 can be a random number 128a in one embodiment, and the module public key 111 can be derived with a key pair generation algorithms 141e using the module private key 112 comprising the random number 128a.

Upon key derivation at step 515, module private key 112 and module public key 111 can be recorded in a nonvolatile memory 101w. Module private key 112 is preferably not transmitted or sent outside module 101. Note that module 101's internal derivation, or processing or creation, of module private key 112 and corresponding module public key 111 can have many benefits. First, module private key 112 does not need to be recorded in any other location than within module 101, and thus may also be considered not shared. Recording module private key 112 only within module 101 avoids potential security risks of (i) storing or recording module private key 112 in other locations, such as with module provider 109, M2M service provider 108, or an installer or end user of module 101, and (ii) transferring module private key 112 to and/or from these other locations. One security risk from storage of module private key 112 outside module 101 is that unauthorized 3rd parties may gain access to the module private key 112.

Also note that over a potential lifetime of a decade or more of operation of module 101, each time a new module private key 112 may be required (for various potential reasons outlined above), the external recording and/or transferring of module private key 112 incurs a potential security risk. Security risks can be compounded if the external location records private keys 112 for a plurality of modules 101. Also, by internally generating private key 112 at step 515, module 101 can overcome significant limitations and costs requiring the distribution of a pre-shared secret key Ki in the form of a SIM card or similar physical distribution of a pre-shared secret key, after module 101 begins operations. In comparison, the use of a shared secret key 510 in the present invention does not require physical distribution of a new shared secret key 510 after module 101 begins operations. Module 101's key derivation could be triggered by either (i) a bootloader program 125, where the bootloader program 125 determines that memory within module 101 does not contain a module private key 112, or (ii) via a module instruction 502 such as a "key generation" command in a response 209 from a server, and other possibilities exist as well.

Note that module 101's generation of keys after deployment and installation may create challenges for authentication of a new module public key 111 with module identity 110, since module 101 may be connecting to server 105 or M2M service provider 108 via the Internet 107. After module 101 creates new module public key 111 and module private key 112 at step 515, at step 516 server 105 can receive a message 208 with the module identity 110, the new module public key 111, and parameters 126. Parameters 126 in message 208 at step 516 can represent the parameters 126 used to generate the module public key 111. The sub-steps for a server 105 to receive a message 208 are also depicted

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and described in connection with FIG. 2 above. Parameters 126 within a message 208 can comprise descriptive values for new module public key 111. Note that at step 516, server 105 does not need to receive new module public key 111 in the form of a certificate 122 (although it could be in the form of a certificate 122). New module public key 111 could be received by server 105 within a string or field within a body 602 of a TCP/UDP packet 601a, illustrated in FIG. 6b below. As depicted in step 516 shown in FIG. 6b below, message 208 can also optionally include a module public key identity 111a, which can be recorded in module database 105k along with module identity 110 and module public key 111a.

According to an exemplary embodiment, a first source (IP:port) number received in a first message 208 at step 516 can be different than a second source IP:port number in a second message 208 at step 518 below, wherein a response 209 send in step 519 below can preferably be sent to the second source IP:port number received in the second message 208 at step 518 in order to traverse a firewall 104 (as depicted and described in connection with packet 209a in FIG. 2). In other words, the proper destination IP:port for a response 209 to a module 101 can change over time, such as the proper destination IP:port changing due to the use of sleep states by module 101 and/or function of a firewall 104. Consequently, according to an exemplary embodiment, a response 209 can utilize a destination IP:port number equal to the source IP:port number received in the last message 208 from module 101 received by server 105.

At step 517, server 105 can authenticate the message 208 received in step 516 using the shared secret key 510 described in step 513. Server 105 could record the shared secret key 510. If step 517 occurs for the first time in a lifetime of module 101, then shared secret key 510 could comprise a pre-shared secret key 129a recorded by server 105 in a module database 105k illustrated in FIG. 1f. If step 517 occurs at subsequent time, then server 105 could have sent shared secret key 510 in a server encrypted data 504 and recorded shared secret key 510 in a module database 105k for later use (such as at step 517). Server 105 can authenticate the message 208 according to message digest, or using the shared secret key 510 as a symmetric key 127 within a symmetric ciphering algorithm 141b, where the successful encryption and decryption of data within message 208 using the shared secret key 510 on both ends could be confirmation that message 208 is authenticated, since both parties would only be able to mutually encrypt and decrypt by sharing the same shared secret key 510.

Other possibilities exist as well for server 105 to use a shared secret key 510 in order to authenticate a message 208 that contains a new module public key 111 (where module 101 contains a new module private key 112). In one embodiment, message 208 in step 516 could include a module digital signature 405, where the module 101 used the shared secret key 510 as a private key to generate the module digital signature 405. After receiving authenticated new module public key 111 in steps 516 and 517, according to a preferred exemplary embodiment, server 105 can preferably only accept and process (A) either incoming (i) a symmetric keys 127 ciphered with a asymmetric ciphering algorithm 141a, and/or (ii) incoming server instructions 414, when (B) the next or a subsequent incoming message 208 from module 101 using module identity 110 also includes a valid module digital signature 405 verified by using the new module public key 111, received at step 516.

According to an exemplary embodiment, shared secret key 510 can be associated with a module public key identity 111a, and shared secret key 510 can be used to authenticate

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a particular value for a module public key identity 111a. In this embodiment, (i) a message 208 with module public key 111 and a first module public key identity 11a may be authenticated using a shared secret key 510, but (ii) a second message with module public key 111 and a second module public key identity 111a may not be authenticated using the same shared secret key 510. Thus, in accordance with an exemplary embodiment, shared secret key 510 can be used for both (i) a single time for authenticating a module public key 111, and (ii) authenticating a module public key 111 with a particular value for the module public key identity 111a. Note that module public key identity 111a can be particularly useful with key revocation, such that a key revocation could specify a particular module public key identity 111a (associated with a particular module public key 111) to be revoked, but other module public keys 111 with different module public key identities 111a could remain valid and not revoked.

Although not illustrated in FIG. 5b, server 105 could operate with a certificate authority 118 in order to utilize a new module public key 111, as described in this paragraph. At step 516, new module public key 111 could be received by server 105 in the form of a uniform resource locator (URL) or domain name for download of a certificate 122 corresponding to the new module public key 111. If new module public key 111 is included in a certificate 122 in this embodiment of step 517 (or a URL to the certificate 122), then module 101 could send server 105 a URL or address on the Internet 107 where server 105 could download the new module public key 111, such as if module 101 had a certificate authority 118 sign the new module public key 111. In this case, (i) the certificate authority 118 (or a separate server than server 105) could perform the steps of 516 and 516 before server 105 conducts step 518 below, and (ii) certificate authority 118 would need some confirmation module 101 using module identity 110 was the correct owner of new module public key 111. Certificate authority 118 could authenticate module 101 using the shared secret key 510 (instead of server 105 authenticating module 101 directly with the shared secret key 510). Other possibilities exist as well for module 101 to utilize shared secret key 510 to authenticate a module public key 111 that has been derived by module 101.

After steps 516 and 517, server 105 can update a module database 105k using the module identity 110 to insert or update the new module public key 111, and parameters 126 associated with new module public key 111. Server 105 may communicate with a plurality of modules 101, and thus could utilize a module database 105k in order to record the new module public key 111 and parameters 126 with the module identity 110. In one embodiment, the module identity 110 could preferably operate as an index within a table of module database 105k in order to speed reads and writes from the table used with module public key 111, parameters 126, and also selecting a symmetric key 127 for a symmetric ciphering algorithm 141b in later messages. As described in FIG. 1g, parameters 126 can include data useful for the operation of cryptographic algorithms 141 and module public key 111. According to a preferred exemplary embodiment, some modules 101 in a system 100 could utilize a first elliptic curve, such as using a first set of ECC parameters 137 or first ECC standard curve 138 within a parameters 126, and other modules 101 could utilize a second and different elliptic curve within a parameters 126, such as a second set of ECC parameters 137 or second ECC standard curve 138.

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After updating the new module public key 111, in step 518 of FIG. 5b, server 105 could receive a second message 208, and the second message 208 can include a module identity 110 and module encrypted data 403. Although not illustrated in FIG. 5b, the second message 208 could also include a module digital signature 405, wherein the module digital signature is created with the new module public key 111 received in step 516. Server 105 could then utilize the steps illustrated in FIG. 4 in order to process the incoming message 208 with the new module public key 111, including using the module identity 110 received in the second message 208 to select the new module public key 111 and subsequently verify a module digital signature 405 using the new module public key 111 and digital signature algorithm 141d. Also as discussed in FIG. 4 in connection with processing a received message 208, server 105 could decrypt the module encrypted data 403 in the second message 208 by using server private key 105c. In one embodiment, the second message 208 as illustrated in FIG. 5b, which could be the next message after authenticating module public key 111 in step 517, could include a symmetric key 127.

The module encrypted data 403 in step 518 could include a symmetric key 127 for utilization with a symmetric cipher 141b. Module 101 could also send sensor data in a module encrypted data 403 at step 518. Or, at step 518 the second message 208 could be a signal for server 105 to use a key derivation function 141f with the server public key 114 and the new module public key 111 (received at step 516) to create a new derived shared key 129b for use with symmetric ciphering algorithms 141b in subsequent messages 208. If the second message 208 in step 518 comprises a signal for server 105 to derive a new derived shared key 129b, then this second message 208 could then optionally leave off module encrypted data 403 and/or a module digital signature 405. The successful use of a new derived shared key 129b (using the new module public key 111 and existing server public key 114) with symmetric ciphering algorithms 141b at subsequent steps by both module 101 and server 105 can indicate to each the communications are mutually authenticated. Second message 208 could also include a server instruction 414, and other possibilities exist as well without departing from the scope of the present invention.

At step 519, server 105 can send a response 209 to module 101, where the response 209 includes server encrypted data 504 and a module instruction 502. Server 105 could take the steps to create and send response 209 as depicted and described in connection with FIG. 5a. Response 209 could be formatted according to the exemplary response 209 illustrated in FIG. 6a. The module instruction 502 could be an acknowledgement 501 that the second message 208 sent in step 518 was received by server 105. At step 520, server 105 can receive a third message 208 with a confirmation 414 to server 105. Confirmation 414 can be used to signal proper execution of module instruction 502, if module instruction 502 comprised an instruction other than an "ACK" or acknowledgement 501. If module instruction 502 in step 519 was an acknowledgement 501 from server 105, then the confirmation 414 may be omitted and in this case step 520 could be skipped.

At step 521 server 101 can determine or evaluate if a new module public key 111 and/or certificate 122 are required for continued operation. One reason for the need of new keys could be the expiration of a certificate 122 for module 101, or the desire to utilize a different set of parameters 126 such as a longer key length for increase security or the use of a different ECC parameters 137 or a different ECC standard curve 138 with cryptographic algorithms 141. As described

elsewhere herein, many other possibilities exist for reasons why module 101 and/or server 105 can prefer for module 101 to utilize a new module public key 111 and new module private key 112. Either server 105 or module 101 may determine that the use of a new module public key 111 and new module private key 112 may be preferred at step 521. If module 101 determines that the use of a new module public key 111 and new module private key 112 is preferred or desirable, module 101 could send server 105 a signal that new keys will be generated either before step 521 or at step 521.

Upon determining new keys are desirable at step 521, then server 105 could instruct module 101 to derive new private and public keys by returning to step 515. Although not illustrated in FIG. 5b, upon determining "yes" at step 521, server 105 could send a module instruction 502 of "new key generation" and also a new set of parameters 126 to utilize with the new module private key 112 and module public key 111. In accordance with exemplary embodiments, module instruction 502, including the "new key generation" instruction and set of parameters 126, can be sent in a response 209 both (i) after module 101 wakes from a sleep or dormant state and sends a message 208 after waking from the sleep or dormant state, and (ii) before the expiration of a firewall port binding timeout value 117 after receiving the message 208. If server 105 determines that new keys are not required or desirable at step 521, server 105 can then proceed to step 312 and wait for additional incoming messages 208 from module 101 or other modules. Step 312 is also depicted and described in connection with FIG. 3.

FIG. 6a

FIG. 6a is a simplified message flow diagram illustrating an exemplary message received by a server, and an exemplary response sent from the server, in accordance with exemplary embodiments. FIG. 6a illustrates exemplary details within message 208 received by server 105 and also response 209 sent by server 105. Message 208 may comprise a TCP/UDP packet 601a sent from module 101 source IP:port 204 to server 105 destination IP:port 207. According to an exemplary embodiment, UDP or UDP Lite formatting for TCP/UDP packet 601a may be preferred. Source IP:port 204 and destination IP:port 207 in message 208 may be included within a header in TCP/UDP packet 601a. Although a single message 208, response 209, module 101, and server 105 are shown in FIG. 6a, system 100 as illustrated in FIG. 2 may comprise a plurality of each of these elements. As contemplated herein, the term "datagram" may also refer to a "packet", such that referring to an element as datagram 601a can be equivalent to referring to packet 601a.

TCP/UDP packet 601a may include a body 602, which can represent the data payload of TCP/UDP packet 601a. The data payload of message 208 can optionally include channel coding 406 as described in FIG. 4 above, if the transport protocol for TCP/UDP packet 601a supports the transmission of bit errors in the body 602 (as opposed to entirely dropping the packet), such as with the UDP Lite protocol. Support for the transmission of bit errors in body 602 by wireless network 102 would be preferred over entirely discarding a packet, since the programs such as module controller 105x could include support for and utilization of channel coding 406. Without UDP Lite formatting, message 208 can alternatively sent by module 101 as a UDP datagram, such as if wireless network 102 (or a wired connection) does not support the UDP Lite protocol. Note that in this case (no support for the transmission of bit errors in a body 602), wireless network 102 and nodes within

Internet 107 would preferably include channel coding on the data link layers of the OSI stack in order to maintain robustness to bit errors at the physical layers of various hops along the path between module 101 and server 105.

Note that if (A) message 208 comprises (i) regular UDP or TCP formatting (i.e. not UDP Lite or similar variations) within an IPv6 network, or (ii) a UDP or TCP format within an IPv4 network with a 603 enabled, then (B) channel coding 406 may optionally be omitted. Checksum 603 can comprise a value to for an integrity check of a packet 601a, and the calculation and use of checksum 603 is defined in IETF standards for TCP and UDP packets. In accordance with a preferred exemplary embodiment, including the use of IPv6 for Internet 107 and a UDP datagram for message 208 and response 209, a checksum 603 sent by module 101 in a message 208 does not equal a checksum 603 in the message 208 received by server 105.

The body 602 can include a module identity 110, module encrypted data 403, and channel coding 406. Although not illustrated in FIG. 6a, body 602 could also include a module digital signature 405, as illustrated in FIG. 6 of U.S. patent application Ser. No. 14/039,401. Module identity 110 is illustrated in FIG. 6a as external to module encrypted data 403, although module identity 110 may optionally only be included in module encrypted data 403, and in this case module identity 110 would not be external to module encrypted data 403 in a body 602. By including module identity 110 as external to module encrypted data 403, server 105 can use the unencrypted module identity 110 in order to select either (i) the appropriate module public key 111 to verify module digital signature 405 if an asymmetric cipher 141a is used within cryptographic algorithms 141, or (ii) the appropriate symmetric key 127 within cryptographic algorithms 141 to decrypt the module encrypted data 403. Module public key 111 and symmetric key 127 may preferably be recorded in a database 105d, such that server 105 can access a plurality of public keys using module identity 110 in body 602 for a plurality of modules 101.

Thus, by including module identity 110 external to module encrypted data 403, server 105 can utilize the module identity 110 to query a database 105d and select the appropriate module public key 111 or symmetric key 127. As noted previously, module identity 110 could comprise a string or number that is uniquely associated with module identity 110, such as a session identity, as opposed to being a module identity 110 that is read from hardware in module 101 such as an IMEI number, Ethernet MAC address, etc. Module identity 110 is illustrated in FIG. 6a as a session identity that is a different representation of module identity 110 of a serial number such as in FIG. 2, but in both cases the values can comprise a module identity 110 since the values can be uniquely associated with module 101 at any point in time.

According to an exemplary embodiment where asymmetric ciphering 141a of module encrypted data 403 is utilized, such as (i) the first message 208 sent by module 101 and (ii) where a symmetric key 127 had not been previously exchanged, module identity 110 can be (a) within module encrypted data and (b) not external to module encrypted data 403. In this case, server 105 can utilize server private key 105c to, in sequence, decrypt module encrypted data 403, extract module identity 110 from the decrypted module encrypted data 403, and then used the module identity 110 to select module public key 111 from module database 105d in order to verify a module digital signature 405. Note that if a module identity 110 is in body 602 and external to module encrypted data 403, then module identity 110 could

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be obfuscated or otherwise ciphered according to a pre-agreed algorithm with server 105, such that server 105 can utilize the obfuscated or ciphered module identity 110 to select a module public key 111 from module database 105k. The value of "[Module Identity String]" shown in FIG. 6a could comprise an obfuscated module identity 110. According to an exemplary embodiment where (i) symmetric ciphering of module encrypted data 403 is utilized, such as after a first message 208 had already been sent by module 101 and a symmetric key 127 had previously been exchanged, then (ii) module identity 110 can be external to module encrypted data 403 and in body 602 in order for server 105 to utilize module identity 110 and select symmetric key 127 from a module database 105k, thereby enabling server 105 to decrypt the module encrypted data 403 using the selected symmetric key 127.

The module digital signature 405 can be calculated using the steps and algorithms described in FIG. 4 above. Module digital signature 405 can be a secure hash string or number, and can be calculated using module private key 112 and digital signature algorithms 141d. Server 105 can verify module digital signature 405 using module public key 111 according to the standard techniques for verifying digital signatures using PKI as described at step 410 in FIG. 4. Note that module digital signature 405 can be useful for server 105 to maintain security, since server public key 114 may be shared and potentially other nodes besides module 101 could attempt to send in encrypted data using server public key 114.

In addition, the module digital signature 405 may optionally be omitted from body 602 after module 101 has previously sent symmetric key 127 in a previous message 208 to the message 208 illustrated in FIG. 6a. In other words, in a series of messages 208, module 101 can preferably change from (i) using asymmetric ciphering 141a with an initial message 208 that includes symmetric key 127 in a module encrypted data 403 (where the initial message 208 also includes module digital signature 405 and module identity 110) to (ii) using symmetric ciphering 141b with subsequent messages 208 without module digital signature 405 in the series (where the subsequent messages 208 can include an obfuscated module identity 110 external to module encrypted data 403 for server 105 to select the appropriate symmetric key 127). The series of messages 208 could begin when the initial message 208 is sent by module 101 and end when expiration time 133 of symmetric key 127 has transpired, and subsequently a new series of messages 208 could begin where the first message 208 in the new series of messages changes back to asymmetric ciphering 141a with initial message 208 that includes symmetric key 127 in a module encrypted data 403 (where the initial message 208 also includes a new module digital signature 405). Other possibilities exist as well without departing from the scope of the present invention.

Using a message 208 with a module digital signature 405 can be both more efficient and overall more secure than digest authentication (such as the digest authentication described in IETF RFC 2069), although using digest-based authentication may be alternatively used. First, the use of a module digital signature 405 requires only a single packet for message 208 and a single packet for response 209 for secure communication between module 101 and server 105. The alternative digest-based authentication would normally require at least 4 packets comprising: (i) message 208, (ii) a challenge to message 208 from server 105 with a security token 401, (iii) a second message from module 101 with a hashed string generated using (i) the challenge, (ii) crypto-

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graphic algorithms 141, and (iii) the module private key 112, and then (iv) an acknowledgement from server 105. The additional messages with digest-based authentication would thereby drain battery life faster or utilize more energy compared to using module digital signature 405.

Second, the use of module digital signature 405 allows a system 100 to be more highly secured since (i) server 105 may need to be connected to the Public Internet 107 and receive packets from a wide range of IP addresses that are not known before messages 208 arrive, and (ii) by using module digital signature 405, server 105 can then preferably not respond to incoming packets and messages without first receiving a properly signed module digital signature 405 (where the module identity 110 associated with module digital signature 405 could also be verified using a certificate 122 and a certificate authority public key 131). By server 105 remaining silent to all packets except packets with a properly signed module digital signature 405, system 100 can thereby remain more secure. In other words, according to preferred exemplary embodiments, server 105 does not send a response 209 to a first message 208 in a series of messages 208 that does not include a validated module digital signature 405 (where the validated module digital signature 405 includes a verified module identity 110), thereby increasing security. Once at least one module digital signature 405 has been received by server 105, then server 105 could use a symmetric key 127 to verify a module identity until a timer expiration 133 for the symmetric key 127. Server 105 could receive a symmetric key using the message 208 illustrated in FIG. 6 of U.S. patent application Ser. No. 14/039,401, and other possibilities exist as well for securely sending and receiving a symmetric key 127.

Module encrypted data 403 can be processed using the steps and algorithms described in FIG. 4. Note that module encrypted data 403 as illustrated in FIG. 6a is shown in a plaintext form for ease of illustration, but actual module encrypted data 403 within body 602 of a packet 601a could be transmitted as binary, hexadecimal, Base64 binary-to-text encoding, or other encoding rules. Note that encryption by module 101 may optionally be omitted, and the server instruction 414 with corresponding data could be included within a message 208 without encryption, such as if security could be maintained at the network level. As one example in this case without encryption, server instruction 414 could be included in body 602 as plaintext. The encryption and/or security could be applied through other means, such as a secure tunnel between module 101 and server 105, although setting up and maintaining a secure tunnel and similar or other means of security may require more processing and bandwidth resources than the efficient techniques described herein.

Module encrypted data 403 can include a server instruction 414, a server identity 206, a module identity 110, a security token 401, a timestamp 604a, and a sensor measurement 604b. The server instruction 414 can represent the purpose of the message 208 for server 105, and FIG. 6a illustrates an "update" for server instruction 414. An update for server instruction 414 could be used to periodically notify server 105 of regular, periodic sensor measurements 604b acquired by a sensor 101f. An update for server instruction 414 may also comprise a periodic report regarding monitored unit 119, and a server instruction 414 is described in FIG. 4. Other server instructions 414 besides an "update" may be included in a module encrypted data 403 within a body 602. The "update" illustrated in message 208 in FIG. 6a can also include a new symmetric key 127, and the module encrypted data 403 illustrated in FIG. 6a may

comprise the use of either an asymmetric ciphering **141a** with public/private keys, or (ii) symmetric ciphering **141b** with a symmetric key **127**.

An initial transmission or negotiation of a symmetric key **127** may preferably utilize asymmetric ciphering **141a** and the use of a public key as an encryption key and a private key as a decryption key. Subsequent transmission of a new symmetric key **127** may utilize either (i) a symmetric cipher **141b** with a previously negotiated but still valid symmetric key **127** (i.e. expiration time **133** has not transpired), or (ii) asymmetric ciphering **141a**. If the data within instruction **414** is longer than the maximum data length supported by a selected asymmetric ciphering algorithm **141a** and the public/private key pair, then module encrypted data **403** within message **208** can be broken up into several sections, such that the data within each section is less than the maximum data length supported by the asymmetric ciphering algorithm **141a** and key length.

Server identity **206** within module encrypted data **403** can be useful for properly identifying that server **105** is the proper recipient and final destination of message **208**. Server identity **206** can be useful if a plurality of servers **105** is utilized by an M2M service provider **108** with potentially hundreds of thousands or millions of modules **101**. In this case, with a plurality of servers **105**, server private key **105c** may represent a private key that is shared among a plurality of servers **105**, since otherwise server **105** may not be able to decrypt module encrypted data **403** if each server **105** in the plurality of servers **105** did not share the common server private key **105c**. Continuing in this example of a plurality of servers **105**, a server identity **206** may represent a server that associated with M2M service provider **108** but not the recipient of message **208**. In this case, (i) a first server **105** could receive message **208** and decrypt message **208** using a common server private key **105c** or symmetric key **127**, and (ii) the first server **105** can forward message **208** to the second server **105** (not shown) with server identity **206**. In this case, the first server **105** can forward message **208** to the second server (not shown) without the encryption applied to module encrypted data **403**, since (i) the second server **105** may not have access to the server private key **105c** and/or symmetric key **127**, or (ii) the first server **105** could have already decrypted the module encrypted data **403** in order to read server identity **206** within module encrypted data **403**.

Module identity **110** within module encrypted data **403** can represent the identity of module **110**, and could represent a serial number read by module **101** from a read-only hardware address. Module identity **110** is described in FIG. 1c and can represent a unique identifier of module **101**. Module identity **110** outside module encrypted data **403** can represent a string or number that is different than a serial number that can be used by module **101** within a module encrypted data **403**. Security token **401** within module encrypted data **403** can represent a random string in order to make message **208** reasonably unique and thus system **100** in FIG. 2 robust against replay attacks. If module encrypted data **403** includes symmetric key **127**, then security token **401** could optionally be omitted since symmetric key **127** can also function as a security token **401**. Security token **401** is described in FIG. 5a. Timestamp **604a** can represent a time value that module **101** sends message **208** or a time value that module **101** acquired sensor data **604b**. Sensor data **604b** is described with the description of a sensor **101f** in FIG. 1e, and sensor data **604b** can represent data module **101** acquires using sensor **101f**. Sensor data **604b** within message **208** may be stored by server **105** in a module database **105k**, or potentially forwarded to another server

(not shown) for additional processing. Sensor data **604b** can comprise a wide range of values for a sensor **101f**/besides the exemplary value of a temperature reading shown in FIG. 6a, including raw sensor data, compressed sensor data, and processed or averaged sensor data. The specific sensor data **604b** shown in FIG. 6a is illustrated to be exemplary and not limiting for sending and receiving sensor data. Sensor data **604b** may also be referred to as a sensor measurement **604b**.

Although not illustrated in FIG. 6a, body **602** or module encrypted data **403** may also include an (i) identity of monitored unit **119**, which may be associated with sensor data **604b**, and/or (ii) a sensor identity **151** associated with sensor data **604b**, such that data from potentially multiple sensors **101f** could be properly identified and recorded. As one example, module **101** could collect sensor data for a plurality of monitored units **119**, and in this case message **208** would preferably include an identity of monitored unit **119** associated with the sensor data **604b**. Or, a sensor **101f** could have a sensor identity **151**, and message **208** could include the sensor identity **151** with the corresponding sensor data **604b** (also illustrated in FIG. 7 of U.S. patent application Ser. No. 14/039,401). As described above, message **208** could also include a symmetric key **127**, as illustrated in FIG. 6 of U.S. patent application Ser. No. 14/039,401.

Note that if (A) module encrypted data **403** exceeds an acceptable length for input or output into asymmetric ciphering algorithms **141a**, such as data within a module encrypted data **403** comprising an exemplary 3000 bits but only a 2048 bit key length is utilized in an exemplary module private key **112** processed with an RSA algorithm **153**, then (B) module encrypted data **403** within body **602** could comprise multiple separate sub-sections for module encrypted data **403**. In this case, each sub-section could comprise data less than the maximum acceptable length for encryption, and the sub-sections could be combined in order to form a module encrypted data **403** within body **602**.

FIG. 6a also illustrates exemplary details within response **209** sent by server **105**. Response **209** may comprise a TCP/UDP packet **601b** sent from server **105** IP:port **207** the IP address **210** and port number **605**, where IP address **210** represents the external IP address of wireless network firewall **104** and port number **605** is the source port in message **208** as received by server **105** (i.e. the source port in message **208** after traversing the firewall **104** illustrated in FIG. 6a). Thus, IP:port with IP address **210** and port number **605** may be different than IP:port **204** in response **209**, since the presence of a wireless network firewall **104** may perform NAT routing, which could change the source IP address and source port number from IP:port **204** to IP address **210** and port number **605** in message **208**, as received by server **105**. The use of wireless network firewall **104** in wireless network **102** may require that response **209** be sent from IP:port **207** to IP address **210** and port number **605** in order to be properly processed by firewall **104** and forwarded to module **101** at IP:port **204**. Source IP:port **207** and destination IP address **210** and port number **605** in response **209** may be included within a header in TCP/UDP packet **601b**. TCP/UDP packet **601b** could comprise a regular UDP packet, a UDP Lite packet, or a TCP datagram, or similar protocols supported by an Internet **107**. TCP/UDP packet **601a** and TCP/UDP packet **601b** can preferably utilize the same protocol.

As noted previously, the use of checksums may be mandatory in IPv6 networks, and thus a response **209** comprising a packet **601b** can include a checksum value **603** (illustrated in message **208** but not response **209**) for the header. The use

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of firewalls such as firewall 104 can change the header values in a packet 601b. In accordance with a preferred exemplary embodiment, a first checksum value 603 within a response 209 sent by server 105 can be different and/or not equal to a second checksum value 603 within the response 209 received by module 101. Likewise, in an exemplary embodiment, a first checksum value 603 within a message 208 sent by a module 101 can be different and/or not equal to a second checksum value 603 within the message 208 received by server 105.

A UDP, TCP, or UDP Lite datagram as a TCP/UDP packet 601b within response 209 may include a body 606. Body 606 may comprise the payload or data within a UDP, TCP, or UDP Lite packet. Body 606 can include a server identity 206, a server digital signature 506, server encrypted data 504, and channel coding 406. Server identity 206 is illustrated in FIG. 6a as external to server encrypted data 504 within body 606, but server identity 206 may optionally be included in server encrypted data 504 instead. Module 101 may communicate with a plurality of servers 105, and server identity 206 as external to server encrypted data 504 can allow module 101 to select the appropriate symmetric key 127 to utilize for decrypting server encrypted data 504 (since each of the multiple servers 105 that module 101 communicates with may utilize a different symmetric key 127).

Also note that the server identity 206 can be similar to module identity 110, such that multiple different values for server identity 206 could be utilized in a system 100, but each of the different values could preferably be uniquely associated with server 105. As one example, server identity 206, outside server encrypted data 504 as illustrated in FIG. 6a, may comprise a session identity or session identifier, as opposed to a different server identity 206 that could comprise a hardware serial number or domain name for server 105. Thus, server identity 206 outside a server encrypted data 504 may be a different string or representation than server identity 206 within server encrypted data 504, but both strings/numbers used for server identity 206 in response 209 could be associated with server 105.

Server digital signature 506 in body 606 can comprise a secure hash signature of a subset of body 606, where the subset of body 606 can comprise server encrypted data 504, and/or server identity 206 as illustrated in FIG. 6a. In other words, processing the secure hash signature can omit (i) server digital signature 506 itself and (ii) channel coding 406 as input into the cryptographic algorithms 141 used to process or verify server digital signature 506. In this manner, module 101 can utilize server digital signature 506 to authenticate that response 209 was sent by server 105. Channel coding 406 in body 606 is also depicted and described in connection with FIG. 5a above.

Body 606 may include server encrypted data 504. Server encrypted data 504 is depicted and described in connection with FIG. 5a above. Server encrypted data 504 may include an acknowledgement 501, wherein acknowledgement 501 can notify module 101 that message 208 has been received by server 105. As illustrated in FIG. 6a, server encrypted data 504 may optionally also include a module instruction 502 for module 101. The module instruction 502 could be a string that contains instructions or configuration parameters for module 101, such as an order to change state, parameters regarding the monitoring of monitored unit 119, server names or addresses, radio frequency parameters, timer values, settings for actuator 101y, etc. A module instruction 502 is depicted and described in connection with FIG. 5a above. The exemplary module instruction 502 illustrated in FIG. 6a comprises a "key generation" 608 instruction for module

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101 derive a new set of keys. The use of a "key generation" 608 instruction was also depicted and described in connection with FIG. 5b above. Other possibilities for a module instruction 502 within a response 209 are possible as well without departing from the scope of the present invention. Although not depicted in FIG. 6a or FIG. 2, if response 209 includes a module instruction 502, according to an exemplary embodiment, module 101 can preferably send a second message 208 to server 105, where the second message 208 includes a confirmation that module instruction 502 was successfully executed or implemented by module 101. This confirmation could be included in a server instruction 414 for server 105 within a second message 208.

Also, although a server encrypted data 504 may preferably be included within a body 606, body 606 may optionally omit server encrypted data 504 and include data from server 105 that is not encrypted, such as plaintext. As one example in this case, acknowledgement 501 could be included in body 606 as plaintext. In addition, although a server digital signature 506 is not illustrated in FIG. 6a, a server digital signature 506 could be included in body 606 and external to server encrypted data 504. In an exemplary embodiment, the inclusion of a server digital signature 506 in a response 209 is illustrated in FIG. 6 of U.S. patent application Ser. No. 14/039,401. The server digital signature 506 may (i) optionally be omitted as well, or (ii) included within server encrypted data 504.

Also, although not illustrated in FIG. 6a, server encrypted data 504 could include a symmetric key 127 for module 101 to utilize with symmetric ciphering 141b in cryptographic algorithms 141 for processing a module encrypted data 403 in subsequent messages 208 and/or responses 209. If server encrypted data 504 includes a symmetric key 127, then server 105 preferably can utilize an asymmetric ciphering 141a with cryptographic algorithms 141 to process the server encrypted data 504 containing the symmetric key 127. An example for the previous sentence could be if message 208 was received without a symmetric key 127 and server 105 can issue the symmetric key 127. As contemplated herein, more than one symmetric key 127 may be used concurrently in a system 100, such as a first symmetric key 127 utilized in symmetric ciphering 141b for a message 208, and a second symmetric key 127 utilized in symmetric ciphering 141b for a response 209. Other possibilities exist as well without departing from the scope of the present invention.

Server encrypted data 504 in a response 209 may include a security token 401. Security token 401 may be a random string and may also be generated by either server 105 or module 101. If security token 401 is generated by module 101, then security token 401 may be included in message 208 and also utilized by server 105 in response 209, as illustrated in FIG. 6. By including security token 401 in acknowledgement 501, system 100 can be made robust to replay attacks since each response 209 can be reasonably unique for each response 209 sent by server 105.

FIG. 6b

FIG. 6b is a simplified message flow diagram illustrating an exemplary message received by a server, wherein the message includes a derived module public key, in accordance with exemplary embodiments. As discussed in FIG. 5b, there can be cases where module 101 derives a new module public key 111 and new module private key 112. On example would be the initial creation of the key pairs by module 101, and many other examples could exist as well. FIG. 6b can illustrate an exemplary format and contents of a message 208 for steps 516 and 517 of FIG. 5b. This

exemplary message 208 can also help to illustrate the significant differences from conventional technology and improvements for efficient and secure communications by utilizing embodiments contemplated herein.

A message 208 illustrated in FIG. 6b using steps 516 and 517 can include (i) sending new module public key 111, a module public key identity 111a, a module identity 110, a server instruction 414, and a set of parameters 126 associated with the new module public key 111 and/or cryptographic algorithms 141 for using the new module public key 111. Exemplary parameters 126 illustrated in FIG. 11 include (i) a secure hash algorithm 141c to utilize in signatures, which could comprise the SHA 256 algorithm as shown (which may also be known as the SHA-2 algorithm), (ii) a selected elliptic curve for use with ECC algorithms 154 or a modulus to use with RSA algorithms 153, and (iii) a time-to-live value for the public key, such as the illustrated “time to live” value of 1 year shown in FIG. 6b. The time value for the validity of new module public key 111 could alternatively be specified in a set expiration date. Other values associated with cryptographic algorithms 141 could be included in parameters 126 as well, and the illustrated values are intended to be exemplary instead of limiting. Other possibilities for data with a message 208 illustrated in FIG. 6b include a parameters 126 including a set of ECC parameters 126, or a specified secure hash algorithm 141c comprising SHA-3 or SHA-512.

Additional values or fields within a message 208 associated with communicating a new module public key 111 with server 105 could include a server instruction 414 of “new public key”. This server instruction 414 could inform server 105 to utilize the new module public key 111 within the message 208. Module public key identity 111a can include a sequence number or identity for the new module public key 111, such that module 101 or server 105 can properly reference and/or select the key from a plurality of module public keys 111 that could be associated with module identity 110. Although module public key identity 111a is illustrated as a separate field in server instruction 414, module public key sequence number 111a could optionally be included in parameters 126, such that the value within parameters 126 specifies the current sequence number or module public key identity 111a for the new module public key 111 included in a message 208.

Other fields and features within a message 208 as illustrated in a FIG. 11 can be similar to the fields presented in FIG. 6a. Since (a) FIG. 6a can also illustrate a first message 208 sent by a module 101 to a server 105, such as after keys are derived in a step 515, then (b) module 101 can read multiple values from RAM 101e or a nonvolatile memory 101w or 101c in order properly construct or format message 208. Each of (i) destination IP:port number 207, (ii) parameters 126, and (iii) shared secret key 510 can preferably be written into nonvolatile memory at step 512 of FIG. 5b, if message 208 in FIG. 6b represents the first message 208 sent by module 101. The source IP:port number 204 can represent a number assigned by an operating system 101h.

If message 208 in FIG. 6b comprises a subsequent time message 208 is received by server 105 (i.e. not a first time message 101 sends a module public key 111), such as after step 521 illustrated in FIG. 5b, then each of (i) destination IP:port number, (ii) parameters 126, and (iii) shared secret key 510 could be updated by server 105 using a module instruction 502 within a server encrypted data 504 before message 208 illustrated in FIG. 6a is received by server 105. In this manner, shared secret key 510 could change from (i) comprising a pre-shared secret key 129a (for a first message

208 after module key derivation) to (ii) comprising a shared secret key that is sent by server 105 within a server encrypted data 504 (for a subsequent message 208 after module key derivation).

After receiving message 208, server 105 can use the unencrypted module identity 110 illustrated in a body 602 of FIG. 6b to select the shared secret key 510 in order authenticate message 208. As described in step 517 of FIG. 5b, server 105 may preferably authenticate message 208 that includes module public key 111 in order to confirm that module public key 111 originated from physical module 101 with a hardware module identity 110 (as opposed to being an imposter submitting the module public key 111). The use of a channel coding 406 is described in connection with FIGS. 4 and 5a, and channel coding may optionally be omitted. If message 208 comprises a UDP Lite packet, then channel coding may optionally be applied within the body 602. If message 208 comprises a UDP packet, then channel coding may comprise sending the exact same UDP packet 601a multiple times, such as an exemplary 3 packets 601a sent at the same time.

Although not illustrated in FIG. 6b, in an exemplary embodiment module public key 111 could also be received in a message 208, where the module public key 111 and parameters 126 can be included in an encrypted format within a module encrypted data 403. As depicted and described in connection with steps 1001 and 1002 of FIG. 10, and also FIG. 11 of U.S. patent application Ser. No. 14/039,401, the security of a system 100 can be further increased by both (i) ciphering module public key 111 and parameters 126, and (ii) only sharing the module public key 111 in a confidential manner with server 105. If module 101 needed a module public key 111 for other purposes, such as obtaining a certificate, then a second, publicly disclosed module public key 111 could be utilized, where the second module public key 111 is different than a module public key 111 using parameters 126 that is sent to a server 105 in a module encrypted data 403.

FIG. 6b also illustrates an exemplary embodiment, where module public key 111 can be authenticated with server 105 using a module digital signature 405. If message 208 comprises a first time module 101 utilizes a step 516 and step 517, such that a module public key 111 has not previously been sent to server 105, then message 208 could include a module digital signature 405 using the shared secret key 510, which could comprise the pre-shared secret key 129a. If message 208 comprises a subsequent time module 101 utilizes a step 516 and step 517, such that a module public key 111 has previously been sent to server 105, then message 208 could include a module digital signature 405 using the previous module private key 112 (i.e. not the new module private key associated with the new module public key 111 in the message 208 shown in FIG. 6b). As noted in FIG. 5b, module digital signature 405 could be omitted, and message 208 with module public key 111 could be authenticated using a message digest algorithm and the shared secret key 129a.

FIG. 7

FIG. 7 is a simplified message flow diagram illustrating exemplary data transferred between a module and an application using a server, in accordance with exemplary embodiments. FIG. 7 includes a system 700 and illustrates an exemplary message 208 from a module 101 to a server 105 and also an exemplary application message 701 between an application 171i and server 105. Note that application message 701 could also be considered as transferred between, sent to, or received from server 105 and application server

171. System 700 can comprise a module 101, a server 105, and an application 171i operating on an application server 171, and these elements may communicate over a network such as the Internet 107. For example, application server 171 may utilize an IP:port number 702 for sending and receiving messages with server 105. The IP address within IP:port number 702 is illustrated as an IPv4 address, but an IPv6 address could be utilized as well, or other addressing schemes are possible. Message flows within a module 101 from a sensor 101f and to an actuator 101y are also included in a system 700 as illustrated in FIG. 7. Message flows within a module 101 could utilize a system bus 101d.

Although not illustrated in FIG. 7, before module 101 sends a module public key 111 to server 105, possibly by using step 516 as illustrated in FIG. 7, module 101 can derive the public and private keys using step 515 and a set of parameters 126. Alternatively, module 101 may have the module public key 111 and module private key 112 generated outside module 101 and loaded into a non-volatile memory 101w. Server 105 can utilize step 516 to receive a module public key 111 from module 101. Server 105 can utilize a step 517 and a shared secret key 510 to authenticate a message 208 that contains the module public key 111 from step 516. Authentication of module public key 111 may be preferred in order to ensure that the module public key 111 is properly associated with the correct physical module 101, and prevent an imposter, hacker, etc. from sending in a fake module public key 111 for module 101. After using step 517 to authenticate module public key 111, server 105 can record module public key 111 and associated module identity 110 (plus optionally a module public key identity 110a) in a module database 105k. Although not illustrated in FIG. 7, server 105 can also send an application message 701 to application 171i after successfully recording module public key 111.

Application 171i operating within an application server 171 can send an application message 701 to server 105, and server 105 can receive the application message 701. Application message 701 could include a module instruction 502, where the module instruction 502 could comprise an actuator setting 706. Although not illustrated in FIG. 7, module instruction 502 as transmitted or sent by application 171i or application server 171 could include a module identity 110 and/or an actuator identity 152. Actuator setting 706 could include a setting value and an actuator identity 152. As one exemplary embodiment, module 101 may have a plurality of actuators 101y that comprise thermostats. Actuator setting 706, where one actuator 101y had an actuator identity 152 of "Left", could comprise an exemplary string like "Left, 25.5", where module 101 would set the "left" thermostat/actuator 101y to 25.5 degrees C. The value "left" could also comprise the actuator identity 152. Other possibilities exist as well without departing from the scope of the present invention, and a thermostat, temperature settings, or actuator identities are not required to use the methods and systems contemplated herein. As discussed below in connection with FIG. 8, actuator setting 706 within an application message 701 could be received within a secure connection data transfer 802 from application server 171. Thus, in an exemplary embodiment, the actuator setting 706 may preferably not be plaintext as transmitted across a network such as the Internet 107 between server 105 and application server 171 in an application message 701.

A module instruction 502 (i) from an application 171i or application server 171, and (ii) within an application message 701 could include other exemplary values or instructions for a module 101, besides the exemplary actuator

setting. According to exemplary embodiments, a module instruction 502 could comprise information for module 101 such as (i) sleep timers or instructions or values for a CPU wake controller 101u, (ii) server address 106 or server identity 206 for communicating with a server 105 (such as sending a different server address 106 for module 101 to utilize in future communications), (iii) a new or updated values for set of data reporting steps 101x, (iv) a new or updated module program 101i, (v) software or firmware for operating system 101h and device driver 101g, (vi) a calibration value for sensor 101f or actuator 101y, (vii) values for a set of parameters 126, (viii) software or settings for radio 101z, (ix) updated cryptographic algorithms 141, (x) a new module private key 112, (xi) a symmetric key 127, (xii) a pre-shared secret key value 129a for use in communicating with a wireless network 102 (where the pre-shared secret key value 129a can be the equivalent of a Ki value in a network supporting ETSI/3GPP standards), (xiii) a value for a module identity 101, (xiv) a security token 401 or settings for using security tokens. Other possibilities exist as well for a module instruction 502 without departing from the scope of the present invention. After receiving module instruction 502 in a response 209 from server 105, module 101 could record the data in module instruction 502 within a nonvolatile memory 101w or RAM 101e.

After receiving application message 701, server 105 can wait for wait interval 703. As depicted and described in connection with FIGS. 2 and 6a, firewall 104 may be present in a system 700 and/or system 100, which could block the transmission or sending of packets from server 105 to module 101 at arbitrary times. In addition, according to exemplary preferred embodiments, module 101 can enter periods of sleep or dormancy using a CPU wake controller 101u in order to conserve energy or the life of a battery 101k, if present. During periods of sleep or dormancy, module 101 may not be able to receive packets from server 105. Consequently, server 105 can preferably wait for the wait interval 703 as illustrated in FIG. 7, before sending response 209 which could include the module instruction 502. As illustrated in FIG. 7, the module instruction 502 could include an actuator setting 706, but module instruction 502 could include other data as well such as the exemplary module instructions 502 described in the previous paragraph.

According to exemplary embodiments, wait interval 703 can vary depending upon module 101 and monitored unit 119, and wait interval 703 could comprise a wide range of values. Module 101 could send a sensor data 604b or a report or a message 208 at exemplary reporting intervals such as every minute, 10 minutes, hour, 6 hours, daily, or longer. Wait interval 703 could be associated with the reporting interval, and the wait interval 703 would end when the next message 208 from module 101 is received. If server 105 supports a plurality of modules 101, wait interval 703 can be associated with the specific module 101 associated with the module instruction 502, possibly by using a module identity 110 in both a message 208 and an application message 701. In other words, server 105 can preferably wait for a message 208 from the specific module 101 associated with the module instruction 502 before sending the response 209 which could include the module instruction 502. Response 209 could be sent using the source and destination IP:port numbers depicted and described in connection with FIG. 2.

Upon the receipt of message 208 from module 101 with module identity 110, the wait interval 703 can end. As illustrated in FIG. 7, message 208 could include a server

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instruction 414. The server instruction 414 in the exemplary embodiment illustrated in FIG. 7 comprises an “update” server instruction 414, and could include a sensor measurement 604b. Sensor measurement 604b could be obtained by module 101 from sensor 101f before sending message 208, and possibly after module 101 wakes from a dormant state using a CPU wake controller 101u. Sensor measurement 604b could be collected by a module program 101i using a system bus 101d. As illustrated in FIG. 6a, a server instruction 414 with sensor data 604b could be within a module encrypted data 403 and received by server 105. Server 105 could utilize the steps illustrated in FIG. 4 to process the received message 208 at the end of wait interval 703. Sensor measurement 604b as used by module program 101i, server 105, application 171i, and/or application server 171 could represent a different string or number at each element, depending upon encoding rules or encoding schemes utilized by each element, but sensor measurement 604b at each location can represent data or a value collected by a sensor 101f.

After processing the received message 208 that could include sensor data 604b, server 105 can send application 171i operating on application server 171 an application message 701 that includes an update instruction 704, where update instruction 704 could include sensor data 604b, module identity 110, and sensor identity 151, if present. Update instruction 704 could include data other than sensor data 604, such as data pertaining to the state of module 101, including subcomponents illustrated in FIGS. 1b and 1e. Using update instruction 704 or a plurality of update instructions 704, application 171i can aggregate data to generate reports for presentation to user 183 or make decisions using service controller 171x. Based on data input in update instruction 704, application 171i could output module instruction 502 in an application message 701. Application 171i could record data received in update instruction 704 within an application database 171k.

After receiving message 208 with server instruction 414, server 105 can send a response 209 to module 101. Note that response 209 is illustrated in FIG. 7 as being sent after sending update instruction 704 to application server 171, but response 209 could also be sent to module 101 before sending update instruction 704 to application server 171. Response 209 can include module instruction 502, where module instruction 502 could comprise actuator setting 706, according to an exemplary embodiment. Module instruction 502 could also comprise other data for module 101 in other exemplary embodiments, as outlined above. Although not illustrated in FIG. 7, response 209 could include module instruction 502 within a server encrypted data 503 using the steps depicted and described in connection with FIG. 5a. Module instruction 502 could also include actuator identity 152 associated with actuator setting 706. Response 209 can be formatted as depicted and described in FIGS. 2 and 6a, such that response 209 can traverse a firewall 104 and be received by module 101 using IP address 204. Network firewall 104 is illustrated as a dashed line in FIG. 7, and may be optionally not be present. But, the use of network firewall 104 may be included in a system 100 and/or system 700 and network firewall 104 may be beyond the control of a module 101, server 105, module provider 109, M2M service provider 108, etc.

After receiving response 209 with the module instruction 502 and actuator setting 706, module 101 can process the response 209, which could also include server encrypted data 503. Module 101 could extract actuator setting 706 from the module instruction 502. Module instruction 502

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could include an actuator identity 152. Module 101 can use a module program 101i to send the actuator setting 706 to the actuator 101y with actuator identity 152. Actuator setting 706 as sent by module program 101i may be in a different format or data structure than actuator setting 706 as sent by application 171i, but both sets of data can achieve the same objective of having an actuator 101y apply a setting. According to one exemplary embodiment, actuator setting 706 as sent by module program 101i could be an analog voltage along a system bus 101d, while actuator setting 706 as sent by application 171i could be a string or number. Or, actuator setting 706 as sent by module program 101i to actuator 101y could be a number in a different format than a number in actuator setting 706 sent by application 171i, application server 171, and/or server 105. Note that as contemplated herein, the term “actuator data” can include or comprise “actuator setting”.

After applying actuator setting 706, actuator 101y can send an acknowledgement to module program 101i. Module program 101i can then send a second message 208 to server 105, where message 208 includes a server instruction 414 of “confirmation”. The server instruction 414 of “confirmation” could be included in a module encrypted data 403 according to a preferred exemplary embodiment. Server 105 can receive the second message 208 with the module encrypted data 403 and decrypt the module encrypted data 403 using a step 413 to extract the server instruction 414 of “confirmation”. The second message 208 may include the actuator identity 152 and/or also the module identity 110. Server 105 can send an application message 701 that includes a confirmation 705, where the confirmation can (i) inform application 171i that the actuator setting 706 sent to server 105 has been properly and/or successfully applied by module 101 and/or actuator 101y. Confirmation 705 could also include module identity 110 and/or actuator identity 152. Application 171i could then send an acknowledgement back to server 105 after receiving the confirmation 705.

According to preferred exemplary embodiments, actuator identity 152 is preferably globally unique, such that that including an actuator identity 152 in any packet would allow a server 105 or application 171i to lookup a module identity 110 and/or module 101 using the actuator identity 152 and a database such as module database 105k. Similarly, a sensor identity 151 may be globally unique, according to preferred exemplary embodiments such that a sensor identity 151 in any packet would allow a server 105 or application 171i to lookup a module identity 110 and/or module 101 using the sensor identity 151 and a database such as application database 171k.

FIG. 8

FIG. 8 is a simplified message flow diagram illustrating exemplary data transferred between a module and an application using a server, in accordance with exemplary embodiments. System 800 can include an application server 171, a server 105, and a module 101 in connected via a network. The network could comprise the Internet 107. Application server 171 could include an application 171i, where application 171i can include logic, algorithms, databases, user interfaces, and programs for managing a plurality of modules 101 with a plurality of users 183. Application server 171 and application 171i may be associated with an M2M service provider 108, and M2M service provider 108 could use application 171i to provide and manage a service with distributed modules 101 associated with a plurality of monitored units 119.

Module 101 can derive a public key 111 and a private key 112 using step 515. Module 101 can derive the public and

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private keys using step 515 and a set of parameters 126. Alternatively, module 101 may have the module public key 111 and module private key 112 generated outside module 101 and loaded into a non-volatile memory 101w. Server 105 can utilize step 516 to receive a module public key 111 from module 101. Server 105 can utilize a step 517 to authenticate a message 208 that contains the module public key 111 in step 516. Authentication of module public key 111 may be preferred in order to ensure that the module public key 111 is properly associated with the correct physical module 101 with a module identity 110, and prevent an imposter, hacker, etc. from sending in a fake module public key 111 for module 101. After using step 517 to authenticate module public key 111, server 105 can record module public key 111 in a module database 105k. Although not illustrated in FIG. 8, server 105 can also send an application message 701 to application 171i after successfully recording an authenticated module public key 111. Although not illustrated in FIG. 8, a module public key 111 received in step 516 may also include a module public key identity 111a in order to track which of a plurality of potential module public keys 111 for a module 101 may be used.

Also, server 105 is not required to receive module public key 111 from module 101 in order to utilize the methods and systems contemplated herein. Instead of receiving module public key 111 in a message 208 from module 101, server 105 could alternatively query another server such as application server 171 or a server associated with certificate authority 118 for either module public key 112 or a certificate 122 associated with module 101 using a module identity 110. In addition, server 105 could have a list or database table of module identities 110 and module public keys 111 loaded into a module database 105k.

After recording module public key 111 and module identity 110, possibly including a module public key identity 111a, server 105 can wait for wait interval 703. Wait interval 703 could represent the time between reports or messages 208 submitted by module 101, and wait interval 703 for an individual module 101 could comprise a wide range of values from several times a second to several days or longer, depending upon the application and/or monitored unit 119. The wait interval 703 can end when server 105 receives a message 208 from module 101 with a module identity 110.

Module controller 105x within server 105 can receive a message 208 that includes a server instruction 414 with sensor data 604b. The sensor data 604b and/or server instruction 414 could be included in a module encrypted data 403, where the module encrypted data 403 can use the module public key 111 submitted in step 516 above and derived by module 101 in step 515. According to one exemplary embodiment, module encrypted data 403 could be ciphered with a symmetric key 127 that is derived shared key 129b from a key derivation function 141f and module public key 111 received in step 516 (and also server public key 114). Module controller 105x can process message 208 using the steps depicted and described in connection with FIG. 4 in order to decrypt the module encrypted data 403 and obtain the plaintext server instruction 414 and plaintext sensor data 604b. Although sensor data 604b is illustrated as the server instruction 414 in FIG. 8, server instruction 414 could have other values such data associated with any of the components for module 101 illustrated in FIG. 1b and FIG. 1e. Server instruction 414 could be a "query" where module 101 queries for information from server 105 or application 171i, or server instruction 414 could be an alarm or error notification outside a regular reporting interval. Other pos-

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sibilities for server instruction 414 exist without departing from the scope of the present invention. Server instruction 414 could also be a periodic "registration" message with no subsystem data for module 101, and a "registration" could be a message for server 105 indicating module 101 is awake and online with Internet 107.

Server 105 can establish a secure connection with application server 171 and application 171i using a secure connection setup 801 and a secure connection data transfer 802. Server 105 can utilize a server program 101i to manage the communication with application 171i and/or application server 171, while a module controller 105x can manage communication with a module 101. Alternatively, server program 101i and module controller 105x can be optionally combined or omitted, such that server 105 performs the actions illustrated in FIG. 8 for server programs 101i and module controller 105x. Likewise, server 105 and application 171 could be combined or operate on the same local area network (LAN) and thus not be connected via the Internet 107. If server 105 and application 171 are nodes within the same LAN or virtual private network (VPN), then the network connection can also be considered a secure connection (without using encryption between the nodes), since packets routed between the nodes may not need to traverse the Internet 107 and thus the network layer could provide security. Although secure connection setup 801 is illustrated in FIG. 8 as occurring after message 208 is received by server 105, secure connection setup 801 could take place before message 208 is received by server 105. Secure connection setup 801 could utilize a secure protocol such as TLS, IPSec, or VPN to establish a secure connection between server 105 and application 171i and/or application server 171, such that data transferred between the two nodes is encrypted and also not subject to replay attacks. As contemplated herein, a secure connection can comprise any of a TLS connection, an IPSec connection, a VPN connection, or a LAN connection between server 105 and application server 171 and/or application 171i, and other possibilities exist as well without departing from the scope of the present invention.

Other secure connections may be utilized as well, including a secure shell (SSH) tunnel, future versions of standard secure connections, or also a proprietary protocol for a secure connection. Secure connection setup 801 as illustrated in FIG. 8 may utilize a TLS protocol, such as TLS version 1.2. Secure connection setup 801 can include the transfer of a certificate 122 for application server 171, and also the transfer of an application public key 171w. Server 105 can utilize application public key 171w to encrypt data received from module 101 in a message 208, such as sensor data 604b. According to one exemplary embodiment, application message 701 could be ciphered with a symmetric key 127 that comprises a derived shared key 129b from (i) a key derivation function 141f(ii) application public key 171w and server public key 114.

The message flow in a secure connection setup 801 also illustrates one benefit of the present invention, where a message 208 can be securely transferred between module 101 and server 105 using a single UDP datagram, while secure connection setup 801 may require a plurality of TCP messages in both directions. In other words, using a secure connection setup 801 between module 101 and server 105 may not be energy efficient for module 101, while using secure connection setup 801 between server 105 and application server 171 can be efficient, since the data from a plurality of modules 101 can be shared over the secure connection setup 801. Also note that since module 101 may

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sleep for relatively long periods such as 30 minutes or longer, a new secure connection setup 801 would likely be required to support a firewall 104 after each period of sleep, and completing the process of a secure connection setup 801 each time module 101 wakes may not be energy or bandwidth efficient for a module 101.

After completing server connection setup 801, server 105 can use a secure connection data transfer 802 to send a first application message 701, where the first application message 701 could include update instruction 704 that includes sensor data 604b that server 105 received in a message 208. Data within the first application message 701 containing update instruction 704 could be ciphered according to the specifications of the secure connection, such as TLS or IPsec, and other possibilities exist as well. Note that server 105 can decrypt a module encrypted data 403 that includes sensor data 604b and subsequently encrypt the sensor data 604b according to the format required by secure connection setup 801 for transfer to application 171i using secure connection data transfer 802. Server 105 can use two different server public keys 114, recorded in the form of a certificate 122 in one embodiment, to with a first server public key 114 used decrypt module encrypted data 403 and a second server public key 114 used encrypt update instruction 704. Server public keys 114 can be used by server 105 in a key derivation function 141f to derive a shared public keys 129b used in a symmetric ciphering algorithm 141b for both secure connection data transfer 802 and module encrypted data 403 (with a different derived shared public key 129b with module 101 and application server 171, respectively).

In another embodiment, server 105 can use the same server public key 114 to both decrypt module encrypted data 403 and encrypt update instruction 704. Other possibilities exist as well for server 105 to use a server public key 114 to (i) encrypt update instruction 704, such as using an asymmetric ciphering algorithm 141a, and (ii) decrypt module encrypted data 403 without departing from the scope of the present invention. As illustrated in FIG. 8, server 105 can receive an acknowledgement 804 after sending the first application message 701, with update instruction 704 that includes sensor data 604b, where acknowledgement 804 can signal that application message 701 with update instruction 704 has been received by application 171i and/or application server 171. Although not illustrated in FIG. 8, the acknowledgement 804 could optionally include a module instruction 502 for module 101.

After receiving message 208, server 105 can then send a response 209. Response 209 could be sent before or after server 105 sends update instruction 704 to application 171i using secure connection data transfer 802. Response 209 can include a server encrypted data 504 that includes a module instruction 502. Module instruction 502 could be processed by server 105, or could be obtained by server 105 from application 171i in an application instruction 701. In other words, a secure connection data transfer 802 may be utilized by a server 105 and an application server 171 to send a second application message 701 to server 105, and be received by server 105, in addition to the sending the first application message 701 from server 105 to application server 171 that is illustrated in FIG. 8.

According to an exemplary preferred embodiment, server 105 waits for a response or acknowledgement 804 from application 171i to application message 701 before sending response 209 to module 101. One reason for waiting for a response or acknowledgement 804 from application 171i is that response or acknowledgement 804 from application

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171i could include a module instruction 502, and the module instruction 502 may preferably be included in a response 209. Other possibilities exist as well without departing from the scope of the present invention.

FIG. 8 can also illustrate a benefit of an exemplary embodiment contemplated herein. According to an exemplary embodiment, (i) server 105 and application server 171 can utilize a first set of cryptographic algorithms 141 for sending and receiving data between server 105 and application server 171, such as with a secure connection data transfer 802, and (ii) server 105 and module 101 can utilize a second set of cryptographic algorithms 141 for sending and receiving data between server 105 and module 101, such as using the second set of cryptographic algorithms 141 for a module encrypted data 403 and/or server encrypted data 504. In an exemplary embodiment, server 105 and application server 171 can use RSA algorithms 153 in the first set of cryptographic algorithms 141, while server 105 and module 101 can use ECC algorithms 154 in the second set of cryptographic algorithms 141. As one example, server 105 can use an (i) RSA-based asymmetric ciphering algorithm 141b and first server public key 114 with the application server 171 to securely transfer a first symmetric key 127 with application server 171, and (ii) an ECC-based asymmetric ciphering algorithm 141b and second server public key 114 with the module 101 to securely transfer a second symmetric key 127 with a module 101.

Other possibilities exist as well for a server 105 to use a different cryptographic algorithms 141 or parameters 126 for each of application server 171 and module 101. (A) Server 105 and application server 171 could use a first set of parameters 126 for use with cryptographic algorithms 141 for an application message 701 with related server digital signatures, while (B) server 105 and module 101 could use a second set of parameters 126 for use with cryptographic algorithms 141 for a module encrypted data 403 and/or server encrypted data 504 and related digital signatures. In order to maximize security between servers such as server 105 and application server 171, the first set of parameters 126 could specify (i) a longer public and private key length, (ii) a shorter key expiration time 133, (iii) a longer secure hash algorithm (such as an exemplary 512 bits), (iv) a longer symmetric ciphering key 127 length (such as an exemplary 192 or 256 bits), (v) the use of or values for RSA algorithm 153 and a modulus, (vi) the use of Diffie Hellman key exchange or a first key exchange algorithm for a key derivation function 141f and key exchange, (vii) the use of or values for a second symmetric ciphering algorithm 141b for symmetric ciphering, (viii) the use of or values for an RSA digital signature algorithm or a second digital signature algorithm, and similar settings.

In accordance with a preferred exemplary embodiment, in order to minimize processing power and/or energy usage required for a module 101, the second set of parameters 126 could specify (i) a shorter public and private key length, (ii) a longer key expiration time 133, (iii) a shorter secure hash algorithm (such as an exemplary 256 bits), (iv) a shorter symmetric ciphering key 127 length (such as an exemplary 128 bits), and (v) the use of an ECC algorithm 154, (vi) the use of or values for an ECC standard curve 138 and/or ECC parameters 137, (vii) the use of or values for ECDH 159 or a second key exchange algorithm for key derivation and exchange, (viii) the use of or values for of a second symmetric ciphering algorithm 141b for symmetric ciphering, (viii) the use of or values for of ECDSA 158 or a second digital signature algorithm for digital signatures, and similar settings. In an embodiment, the first set of parameters 126

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(which can be used by server 105 and application server 171) and the second set of parameters 126 (which can be used by server 105 and module 101) can both specify the use of elliptic curve cryptographic algorithms 141, but with different sets of parameters 126 such that the first set of parameters 126 is selected for server to server communications, and the second set of parameters 126 is selected for communications between a server 105 and a module 101. In another embodiment, the first set of parameters 126 and the second set of parameters 126 can both specify the use of RSA based cryptographic algorithms 141, but with different sets of parameters 126 such that the first set of parameters 126 is selected for server to server communications, and the second set of parameters 126 is selected for communications between a server 105 and a module 101.

In this manner, the use of cryptographic algorithms 141 between (i) server 105 and application server 171 and (ii) server 105 and module 101 can be optimized given different constraints for processing power and energy consumption for server 105, application server 171, and a module 101. In addition, an application server 171 may use cryptographic algorithms 141 and parameters 126 that may not be compatible with cryptographic algorithms 141 and parameters 126 used by a module 101, and server 105 can use cryptographic algorithms 141 and parameters 126 to enable a translation or conversion of encrypted data and digital signatures between a module 101 and an application server 171, thereby establishing connectivity between a module 101 and an application server 171 through a server 105. According to an exemplary embodiment, server 105 can function as a gateway between application server 171 and/or application 171i and a plurality of modules 101.

FIG. 9

FIG. 9 is a simplified message flow diagram illustrating exemplary data transferred between (i) a server and an application and between (ii) a server and a module, in accordance with exemplary embodiments. An application server 171, a server 105, and a module 101 can send and receive data illustrated in FIG. 9. Application server 171 can include application 171i and use an Internet Protocol address and port (IP:port) number 903 for sending and receiving data with server 105. Server 105 can include a server program 101i and a module controller 105x, where server program 101i can access a first server IP:port number 901 for communicating with application server 171, and module controller 105x can access a second server IP:port number 207 for communication with module 101. In accordance with a preferred exemplary embodiment, multiple modules 101 can send data to server IP:port number 207, and thus server 105 and/or a module controller 105x can use a single IP:port number 207 to communicate with a plurality of modules 101. In addition, server 105 could specify that one subset of modules 101 communicate with a first IP:port number 207, and a second subset of modules 101 communicate with a second IP:port number 207, etc. In another embodiment, server 105 could use multiple Internet Protocol addresses for sending and receiving data with a module 101, although a given module 101 can preferably send a message 208 to IP:port number 207 and receive a response 209 from the IP:port number 207, and a different module 101 could use a different value for IP:port number 207, including potentially a different IP address 106. Module 101 can utilize an IP:port number 204 for sending and receiving data with server 105.

As illustrated in FIG. 9, a symmetric firewall 104 could be included between module 101 and server 105, and the of IP addresses and port numbers in packets between server 105

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and module 101 illustrated in FIG. 9 could also represent routing if a firewall 104 is present and functions as a symmetric firewall without NAT routing. In this case, firewall 104 may not perform network address translation on source and destination IP addresses, but rather filter packets based on pre-determined rules. For example, a firewall 104 that is a symmetric firewall could drop inbound packets from IP:port number 207 to module 101 unless module 101 had previously sent a packet to IP:port number 207 within a firewall port binding timeout value 117. Alternatively, a firewall 104 may be optionally omitted, and in this case the destination address in packets sent from server 105 to module 101 could include the IP address 202 of module 101, which is also the case illustrated in FIG. 9. In other words, FIG. 9 illustrates an exemplary routing of packets in the cases that (i) firewall 104 is a symmetric firewall, and (ii) firewall 104 is optionally not present.

Server 105 can receive a message 208 from a module 101. Server 105 can use a module controller 105x to receive the message, and module controller 105x could also be identified as a process operating on server 105 that binds to the port number in IP:port 207, which could include a port number 205. Message 208 could include module identity string 904, which could represent a temporary or transient string or number used by module 101 and server 105 to associate and identify message 208 with module identity 110. Module identity string 904 could also comprise a module identity 110. Server 105 can use module identity string 904 to select a symmetric key 127 in order to decrypt module encrypted data 403, since module identity string 904 may preferably be not encrypted. Server 105 and module 101 could use an algorithm within cryptographic algorithms 141 in order to process a module identity string 904, whereby the module identity string 904 can be converted between (i) a module identity 110 in a form such as a serial number or IMEI within module 101 and/or server 102, and (ii) a module identity string 904 in a message 208 that can traverse the Internet 107.

Message 208 as received by server 105 can also include a server instruction 414 within a module encrypted data 403, where the module encrypted data 403 could be ciphered using a symmetric key 127. The server instruction 414 illustrated in FIG. 9 can be an exemplary "update" instruction, where the "update" instruction can include a security token 401 and sensor data 604b. Sensor data 604b can include a sensor identity 151 and a sensor measurement. Server instruction 414 within a message 208 could include many other values besides an update, including a registration, a query, an alarm or error notification, configuration request, software request, confirmation, or other values also depicted and described in connection with a server instruction 414 in FIG. 4. Although message 208 is illustrated as a UDP datagram 601a in FIG. 9, message 208 could also be transmitted as a TCP datagram or other Internet transport protocols including Datagram Congestion Control Protocol (DCCP) and Stream Control Transmission Protocol (SCTP). A security token 401 can comprise a random number 128a processed by a random number generator 128 and can be preferably not reused and therefore can keep message 208 unique and not subject to replay attacks. Since a UDP protocol may be implemented for message 208, and the connectionless UDP protocol may require a module 101 to send retransmissions of a UDP datagram 601a for message 208, if module 101 does not receive a response 209 within a specified timer period.

According to an exemplary preferred embodiment, server 105 can include a timer 905, such that multiple UDP

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datagrams 601a received within the timer 905 period may be processed, but datagrams received outside the expiration of the timer 905 would be dropped. Note timer 905 can be particularly useful for security of a system 100 when module 101 may transmit multiple copies of UDP datagram 601a. Module 101 may transmit multiple copies of a UDP datagram 601a in order to implement forward error correction and compensate for any packet loss on the Internet 107 or possibly with wireless network 102. The UDP datagram 601a may also be sent as a UDP Lite datagram with channel coding 406. Server 105 can start timer 905 when the first UDP datagram 601a in message 208 is received, and discard UDP datagrams 601a for message 208 after the timer 905 expires, such as after an exemplary 2 seconds although other possibilities exist as well. In this manner (i) module 101 can securely send multiple copies of the same UDP datagram 601a in message 208, and (ii) server 105 can remain robust against replay attacks. Server 105 can also reset the timer 905 to a zero value upon sending response 209, and the timer value 905 could start again upon the receipt of a first UDP datagram 601a in the next message 208.

If the UDP Lite protocol is utilized for message 208 with multiple copies of UDP Lite datagram 601a received, then each UDP Lite datagram 601a could be different, depending on the presence of bit errors in the datagram, and thus server 105 can use timer 905 to collect the multiple copies of UDP Lite datagram 601a within the timer 905 period and process the multiple packets received, including combining the data across multiple packets, in order to eliminate bit errors within the datagrams and collect an error-free message 208.

After receiving message 208, server 105 use the steps outlined in FIG. 5a to process message 208 and read the plaintext server instruction 414, such as the sensor data 604b illustrated in FIG. 9. Other possibilities exist as well for sensor data 604b or values or information inside a server instruction 414. Server 105 can then send or transmit a first application message 701 to application server 171 that includes data received from the server instruction 414 from module 101 in message 208. The data received in the server instruction 414 from module 101 could be included by server 105 in an update instruction 704. An application 171i operating within application server 171 or associated with application server 171 could receive the first application message 701. The first application message 701 could be formatted according to a TCP datagram 902, although other possibilities exist as well including UDP.

In accordance with an exemplary preferred embodiment, the first application message 701 may include an update instruction 704 with sensor data 604b, although update instruction 704 could also contain or include other data pertaining to module 101 besides sensor data 604b, such as a state of a component with module 101, a state of a software routine, variable, or parameter associated with module 101. The first application message 701 sent from server 105 to application server 171 could be a datagram within a secure connection data transfer 802 as illustrated in FIG. 8. Sensor data 604b could be sent by server 105 using application server public key 171w, such as either (i) mutually deriving a common shared key 129b between server 105 and application 171i using a key derivation function 141f, where the shared key 129b could function as a symmetric key 127 with a symmetric ciphering algorithm 141b, or (ii) server 105 sending a symmetric key 127 to application server 171 using an asymmetric ciphering algorithm 141a and the application server public key 171w. Message 805 in FIG. 8 with the label of "Client Key Exchange" can comprise server 105 sending a symmetric key 127 (or value or parameter 126 for

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deriving symmetric key 127) to application server 171, where the symmetric key 127 can be used by server 105 to encrypt update instruction 704 illustrated in FIG. 9.

In accordance with an exemplary preferred embodiment, application message 701 may include (i) module identity 110 encrypted within secure connection data transfer 802 and also a server identity 206 that is not encrypted. In this manner, application server 171 can use server identity 206 to select a symmetric key 127 (possibly sent in message 805 as described in the paragraph above) in order to decrypt the encrypted data in update instruction 704. Although not illustrated in FIG. 9, in accordance with another exemplary embodiment, both a message 208 and the first application message 701 may also include a module digital signature 405. Server 105 can forward the module digital signature 405 received in a message 208 with sensor data 604b to the application server 171 in the first application message 701 illustrated in FIG. 9. The module digital signature 405 in a first application message 701 does not need to be encrypted. The application server 171 can verify the module digital signature 405 using step 411 of FIG. 4 (using a module public key 111). In this manner, application 171i can verify that module 101 originated the sensor data 604b, even though application server 171 received the application message 701 from server 105.

Application server 171 can receive the first application message 701 sent by server 105 and process the message. The message processing by application server 171 could use steps similar or equivalent to the steps utilized by server 105 illustrated in FIG. 4, in order to extract a plaintext application instruction 704. Although not illustrated in FIG. 9, application 171i could record data received within application instruction 704 and record the data in an application database 171k. Application 171i could use the data received in application instruction 704 or a plurality of application instructions 704 to generate reports, graphs, emails, or other user information for a user 183.

Upon processing the information within application instruction 704, application 171i or application server 171 could send a second application message 701 to server 105, as illustrated in FIG. 9. The second application message 701 could be sent using a secure connection data transfer 802, and could include a module instruction 502 and a module identity 110. The second application message 701 can use the IP:port number 903 as a source IP:port number for the second application message 701, where IP:port number 903 also represented a destination IP:port number for the first application message 701. The second application message 701 can use the IP:port number 901 as the destination IP:port number, where IP:port number 901 was the source port number in the first application message 701. The module instruction 502 within the second application message 701 can comprise could include an actuator setting 706. The module instruction 502 within the second application message 701 can comprise other data or module instructions 502 for a module 101 that do not include an actuator setting 706, such as the exemplary data depicted and described in connection with FIG. 5a.

Either server 105 or application server 171 could use the application server public key 171w to process the second application message 701. As one example, server 105 and/or application server 171 could use a key derivation function 141f to derive a key, where key derivation function 141f used application server public key 171w. The derived key could be used to encrypt and/or decrypt the module instruction 502 in the second application message 701. Other possibilities exist as well for the second application mes-

sage 701 to use the application server public key 171w, such as server 105 sending a symmetric key 127 (used to encrypt and/or decrypt module instruction 502 in the second application message 701), where they symmetric key 127 was ciphered using the application server public key 171w.

Server 105 can receive the second application message 701, and the message could be received using an IP:port number 901. Although an IPv4 address is shown in FIG. 9, and IPv6 address could be utilized as well. Server 105 could decrypt a body 602, that contains module identity 110 and a module instruction 502, using algorithms specified according to a secure connection data transfer 802. According to an exemplary embodiment, a secure connection data transfer 802 between a server 105 and an application server 171 could also comprise the steps for encrypting/decrypting and signing/verifying that are depicted and described in connection with FIG. 4 and FIG. 5a, and thus secure connection data transfer 802 could also optionally use the same steps and procedures between server 105 and application server 171 that are contemplated between server 105 and module 101. As one example, the application message 701 packets illustrated in FIG. 9 sent between server 105 and application 171 could be formatted to UDP and include a server encrypted data 504. As depicted and described in FIG. 8, a first set of parameters with cryptographic algorithms 141 could be used with an application message 701 and a second set of parameters 126 with cryptographic algorithms 141 could be used with server encrypted data 504 and/or module encrypted data 403.

After extracting a plaintext module instruction 502 and module identity 110 from a body 602 in the second application message 701, server 105 can take steps to process the data within a response 209 for module 101. Server 105 can record or query for information pertaining to module 101 using module identity 110 in a module database 105k. In accordance with exemplary embodiments, server 105 can use module identity 110 received in the second application message 701 to select (i) a symmetric key 127 used by module 101 for encrypting and/or decrypting a server encrypted data 504 that can include the module instruction 502, (ii) a destination IP:port number 204 for sending a response 209, (iii) a source IP:port number 207 for sending a response 209, (iv) a determination if a wait interval 703 is required before sending response 209, (v) a security token 401, and (vi) a set of parameters 126 for use with a cryptographic algorithms 141 in communications with module 101. In one embodiment, different modules 101 connected to server 105 may use different parameters 126, and server 105 can select the parameters 126 using (i) the module identity 110 received in the second application message and (ii) a module database 105k. Server 105 can also use module identity 110 received in the second application message 701 to select (vii) a transport protocol for a response 209, such as TCP, UDP, or UDP Light, and (viii) a channel coding 406 parameter such as a block code, turbo code, or forward error correction coding scheme. Server 105 can use module identity 110 received in application message 701 to format and/or send a response 209 to module 101.

According to a preferred exemplary embodiment, server 105 may receive an application message 701 with data for a module 101 at arbitrary times. Server 105 could also receive an application message 701 at a time when a first application message 701 with module identity 110 has not (i) previously been sent by server 105, (ii) or sent in a comparably long time such as a day or a week. As noted previously, server 105 may not be able to send a module instruction 502 to module 101 at arbitrary times, because of either (i) a sleep or

dormant period for module 101, and/or (ii) the presence of a firewall 104. Thus, server 105 may need to (i) receive a message 208 from module 101 (such as upon waking after a sleep period after a firewall port binding timeout value 117 period since the last message 208) before (ii) sending a module instruction 502. Consequently, according to a preferred exemplary embodiment, server 105 can use module identity 110 received within an application message 701 to determine (i) if server 105 should wait until a wait interval 703 expires before sending response 209 (where the wait interval 703 can end upon receipt of a message 208 from a module 101 with the module identity 110 received in the application message 701) or (ii) if server 105 can send response 209 right away (such as a firewall port binding timeout period 117 has not expired), where response 209 includes the module instruction 502 received in the application message 701.

After (A) using module identity 110 received within application message 701 to select values within a response 209 and timing for sending a response 209, then (B) server 105 can send response 209 as illustrated in FIG. 9, where the specific response 209 in FIG. 9 is exemplary. Response 209 can include a server encrypted data 504. Server encrypted data 504 can include module instruction 502. The exemplary response 209 illustrated in FIG. 9 includes an actuator setting 706 within module instruction 502, but other possibilities exist as well. Note that the use of server encrypted data 504 is optional within a response 209, and server 105 could send module instruction 502 as plaintext. However, in this case of module instruction 502 being sent as plaintext, server 105 can preferably include a server digital signature 506 such that module 101 can verify the server digital signature 506 using the server public key 114 and confirm the module instruction 502 was transmitted by server 105. In accordance with exemplary preferred embodiments, (i) a message from module 101 to server 105 that does not include a module encrypted data 403 preferably includes a module digital signature 405, and (ii) a response 209, message sent back, datagram, or packet from server 105 to module 101 that does not include a server encrypted data 504 preferably includes a server digital signature 506. If data is not encrypted within a packet and the packet includes plaintext instructions such as a module instruction 502 or a server instruction 414, then, in accordance with preferred exemplary embodiments, the receiving node can preferably verify the identity of a sender using a digital signature included in the packet.

Response 209 sent from server 105 to module 101 could include a checksum 603. Since firewall 104 may comprise a symmetric firewall 104 (that may not perform network address translation routing), the destination address within IP:port 204 in response 209 illustrated in FIG. 9 may match the IP address 202 used by module 101. In this case, where the destination IP:port in response 209 includes IP address 202, a checksum 603 sent by server 105 can be equal to a checksum 603 received by module 101. In accordance with exemplary embodiments, response 209 is transmitted or sent by server 105 within a firewall port binding timeout value 117 after message 208 was received by server 105. In other words, if a firewall port binding timeout value 117 was equal to an exemplary 20 seconds for UDP packets, the response 209 illustrated in FIG. 9 would preferably be sent in less than 20 seconds after receiving the last message 208.

FIG. 10

FIG. 10 is a flow chart illustrating exemplary steps for a server to receive a module instruction within an application message, and for the server to send the module instruction

to a module, in accordance with exemplary embodiments. Since an application 171i operating with an application server 171 may utilize a different set of protocols for communications than a module 101, server 105 can provide connectivity between module 101 and application 171i. As illustrated in FIG. 8 and FIG. 9 above, a server 105 can receive an application message 701 from an application server 171. The application server 171 and/or application 171i could be identified by the source IP address in an application message 701 received by server 105. Application message 701 could include encrypted data using a secure connection data transfer 802, where a body 602 within a packet could include a module instruction 502 and a module identity 110. As illustrated in system 199 in FIG. 1i, server 105 can support a network with a plurality of modules 101, and thus a module identity 110 within an application message 701 can be useful to (i) select the proper destination of module instruction 502, and (ii) other values for sending a response 209 to module 101 as depicted and described in connection with FIG. 9 above.

At step 1001, server 105 can preferably utilize the protocol for the secure connection data transfer 802 (such as TLS illustrated in FIG. 8) to extract the plaintext module instruction 502 and module identity 110. Server 105 could use a first symmetric key 127 with application server 171, such as (i) a first symmetric key 127 derived or transmitted with message 805 and (ii) a symmetric ciphering algorithm 141b. After extracting plaintext from application message 701, server 105 can record the data in a module database 105k, or simply store the data for further processing in a memory 101e. Although not depicted in FIG. 10, server 105 could use a message pre-processor 105y to send and receive data with application server 171, where the message pre-processor could comprise a program or library such as a TLS library, and IPsec library, an SSH library, etc.

Server 105 can then wait for a wait interval 703, where server 105 waits for an incoming message from module 101. Server 105 may need to wait for the wait interval 703 because the module may sleep or be dormant, and also a firewall 104 may block inbound packets or datagrams from server 105 to module 101 if module 101 had not previously sent a packet within a firewall port binding timeout value 117. After the wait interval 703, server 105 can use step 503 to encrypt module instruction 502 using a second symmetric key 127 and a security token 401, where the second symmetric key 127 is different than the first symmetric key 127. As illustrated in FIG. 5a, the output of step 503 can be a server encrypted data 504. Although step 503 is illustrated as after wait interval 703 in FIG. 10, step 503 could also take place either (i) before wait interval 503 or (ii) concurrently with wait interval 703.

According to exemplary embodiments, a first symmetric key 127 used by server 105 and application server 171 is different than a second symmetric key 127 used by module 101 and server 105. In addition, according to an exemplary embodiment, server 105 may use an RSA algorithm 153 for asymmetric ciphering 141a in packets with application server 171 and an ECC algorithm 154 for asymmetric ciphering 141a in packets with a module 101. Thus, according to an exemplary preferred embodiment, server 105 can utilize (i) a first certificate 122 with an RSA-based server public key 114 for use in communication with application server 171i and (ii) a second certificate 122 with an ECC-based server public key 114 for use in communication with a module 101. In an exemplary embodiment, the first symmetric key 127 is associated with a first symmetric ciphering algorithm 141b between server 105 and applica-

tion server 171, and the second symmetric key 127 is associated with a second symmetric ciphering algorithm 141b between server 105 and module 101, and the first and second symmetric ciphering algorithms 141b are different. As depicted and described in connection with FIG. 8, the first and second symmetric ciphering algorithms 141b may use different parameters 126, such as a first set of parameters 126 with the first symmetric ciphering algorithms 141b and a second set of parameters 126 with the second symmetric ciphering algorithms 141b.

Server 105 can receive a message 208 from module 101, where the module identity 110 or module identity string 904 in message 208 could represent a number or string associated with the module identity 110 in application message 701. Note that the exact string, number, or digits in module identity 110 or module identity string 904 in message 208 does not need to match the exact string, number, or digits for module identity 110 in application message 701, and the two messages could use different encoding schemes or values for module identity 110. As one example, module identity 110 in application message 701 could represent a serial number for module 101, while module identity 110 in message 208 could represent a session identity. Other possibilities exist as well for a string or number within a module identity 110. Server 105 can preferably uniquely associate module identity 110 in an application message 701 with module identity 110 in a message 208.

After receiving message 208, server 105 can send the server encrypted data 504 processed in step 503 above within a response 209. A server encrypted data 504 within response 209 could include the module instruction 502, where module instruction 502 was received in the application message 701. Note that module instruction 502 within response 209 does not need to be the exact same string, number, or binary digits as module instruction 502 received by server 105 in application message 701. As one example, application message 701 and response 209 could use different coding schemes (such as ASN.1 for response 209, and plaintext for application message 701, although other possibilities exist as well). As illustrated in FIG. 10, module instruction 502 within an application message 701 can preferably represent an equivalent action for module 101 as a module instruction 502 within response 209. For example, module instruction 502 in both application message 701 and response 209 could instruct module 101 to (i) throw a switch, (ii) sleep for an interval, (iii) adjust a power level, and other possibilities exist as well. As described above in FIG. 9, the use of encryption within response 209 could optionally be omitted, but in this case response 209 may include a server digital signature 506 with module instruction 502.

After sending response 209, at step 1002 the server 105 may preferably receive a confirmation from module 101 that the module instruction 502 had been successfully received and/or successfully applied. The confirmation could be received in the format of a second message 208 from module 101 with a server instruction 414, where the server instruction 414 is a "confirmation". Other data regarding the execution of module instruction 502 by module 101 could be included in the confirmation at step 1002, such as a timestamp 604a when the module instruction 502 was executed. After receiving the confirmation from the module 101, server 105 can preferably send a second application message 701 to an application server 171 and/or application 171i with a confirmation 705. The confirmation 705 could be sent using a secure connection data transfer 802. In accordance with exemplary embodiments, the application message 701

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sent from server 105 to application server 171 in the form of a confirmation 705 can include the timestamp 604a.

In an exemplary embodiment, the reliable and secure transmission of timestamp 604a from module 101 to application server 171 through server 105 may be useful for proper management of a monitored unit 119. Due to any sleep or dormant states of module 101, plus periodic outages and recovery of wireless network 102, a first time value that module 101 executes module instruction 502 may be significantly different than a second time value that application server 171 sent the module instruction 502. Consequently, application server 171 may preferably receive a timestamp 604a sent by module 101 in an application message 701 from server 105, and the application message 701 could comprise a confirmation 705.

Although not illustrated in FIG. 10, server 105 could then continue listening on or monitoring (i) IP:port 901 for additional incoming application messages 901 from application server 171, and (ii) IP:port 207 for additional incoming messages 208 from a module 101. Although not illustrated in FIG. 10, module instruction 502 may optionally be encrypted such that server 105 may not be able to read plaintext within module instruction 502, and in this case step 1001 illustrated in FIG. 10 would be bypassed. For example, module instruction 502 may be encrypted with the module public key 111, and thus module instruction 502 may only reasonably be read by module 101. Even if module instruction 502 cannot be read in plaintext form by server 105 upon receiving application message 701, module identity 110 within application message 701 would preferably be in a form where server 105 can (i) process the module identity 110 into plaintext (as a minimum in order to route the message to module 101 among a plurality of modules 101), or (ii) simply read the module identity 110 from a body 602 in the application message 701.

In this embodiment where step 1001 is omitted in FIG. 10, the application server 171 can use a module public key 111 and an asymmetric ciphering algorithm 141a to encrypt the module instruction 502 shown in the body 602 of the application message 701 illustrated in FIG. 9. The application server 171 can also include a digital signature of the module instruction 502 using the application server private key 171r and a digital signature algorithms 141d. The encrypted module instruction 502, module identity 110, and digital signature can be sent to the server 105 in an application message 701 using the first step shown in FIG. 10. The application message 701 can also include an identity of the application server.

Continuing in this embodiment where step 1001 is omitted in FIG. 10, the server 105 can then use the waiting interval 703 until a message 208 is received from a module 101. In this case where step 1001 is omitted in FIG. 10, then step 503 can also be omitted since the module instruction 502 is already encrypted with the module public key 111 (by the application server 171). After skipping step 503 and receiving the message 208, the server 105 can then send the encrypted module instruction 502 and digital signature (signed by the application server 171) to the module 101 in a response 209, as shown in FIG. 10. The module 101 can read receive the response 209, read the identity of the application server, select a public key 171w of the application server 171, verify the digital signature of the module instruction 502, and decrypt the module instruction 502 using the module private key 112 and an asymmetric ciphering algorithms 141a. The module 101 can then apply the module instruction 502 and send a message 208 with a confirmation at step 1002. The confirmation at step 1002 can

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include a timestamp 604b, which the server 105 can send to the application server 171. In this manner, the module 101 may receive instructions from the application server 171 that are not encrypted by the server 105.

FIG. 11

FIG. 11 is a flow chart illustrating exemplary steps for a server to communicate with an application and a module, in accordance with exemplary embodiments. FIG. 11 includes a combination of different exemplary embodiments contemplated in the present invention, including (i) receiving a first module encrypted data 403 with a first sensor data 604b from a module 101 using a first public key 111, (ii) sending the first sensor data 604b in a first application message 701, (iii) sending a module instruction 502 for a module 101 to derive a new public and private key pair using a set of parameters 126, (iv) receiving a second module encrypted data 403 with a second sensor data 604b from module 101 using the second public key, and (iv) sending the second sensor data 604b in a second application message 701.

Server 105 can receive a first module public key 111 at step 516. The first module public key 111 can be in a message 208 that includes a module identity 110 and first parameters 126, where the parameters can provide values associated with the first module public key 111 such as an elliptic curve name or defining equation, a modulus for an RSA key, a time-to-live value, a certificate authority 118 name, etc. According to an exemplary embodiment, a set of parameters 126 can include a module public key identity 111a, in addition to other values. Server 105 can receive the first module public key 111 at step 516 in the form of a certificate 122, although a certificate 122 is not required. Although not illustrated in FIG. 11, module public key 111 could optionally be encrypted in a module encrypted data 403, as depicted and described in connection with Step 1001 of FIG. 10 in U.S. patent application Ser. No. 14/039,401. In addition, the submission of the first module public key 111 at step 516 could be authenticated using step 517 of FIG. 5b of the present invention. In this manner, server 105 can ensure that the first module public key 111 is properly associated with module identity 110 and/or module 101 (i.e. prevent an incorrect submission of the first module public key 111 or even the potential malicious submission of the first module public key 111). In accordance with a preferred exemplary embodiment, the first message 208 received at step 516 can also include a module public key identity 111a, so that server 105 can properly keep track of multiple different module public keys 111 used by a module 101 over time, such as module 101 periodically rotating public/private key pairs in order to enhance security.

At step 1101, server 105 can receive a second message 208 that includes a first module encrypted data 403, where the first module encrypted data 403 was processed by server 105 using the first module public key 111 and first set of parameters 126 received in step 516. In accordance with an exemplary preferred embodiment, server 105 can use the first module public key 111 to process the first module encrypted data 403 by (i) mutually deriving a common shared secret key 129b as a symmetric key 127 for use between server 105 and module 101 using a key derivation function 141f with the first module public key 111 as an input into the key derivation function 141f, and (ii) server 105 sending a symmetric key 127 to module 101 where (ii.a) the symmetric key 127 was ciphered using an asymmetric ciphering algorithm 141a and the first module public key 111 and (ii.b) the first module encrypted data 403 was ciphered using the symmetric key 127. Note that the second message 208 could be optionally sent without ciphering or

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encryption, and in this case the second message 208 could use the first module public key 111 to include a module digital signature 405 in the second message 208. The second message 208 can include a sensor data 604b or other server instruction 414. According to an exemplary embodiment, the second message 208 may also preferably include a module identity 110 or a module identity string 904 outside of the module encrypted data 403, so that server 105 can select the proper key in order to decrypt the module encrypted data 403.

At step 1102, server 105 can use an application message 701 to send the sensor data 604b from a sensor 101f with module 101 to an application server 171 and/or an application 171i. As illustrated in FIG. 8 and FIG. 9, the application message 701 can use a secure connection data transfer 802, and could comprise an update instruction 704. The application message 701 can include both a module identity 101 and a server identity 206, and the server identity 206 can be useful for application server 171 since the application server 171 could receive a plurality of application messages 701 from a plurality of servers 105, each using a different key for ciphering. Although not illustrated in FIG. 11, steps 1101 and 1102 could be completed in series multiple times before proceeding to step 1103, such as module 101 sending multiple messages 208 with sensor data 604b over several days or longer, and server 105 can correspondingly send the data to an application server 171.

At step 1103, server 105 can process a module instruction 502 for module 101 to derive a second module public key 111 and a second private key 112. Potential reasons for the use of a new public and private key by module 101 are described in connection with FIG. 5b and elsewhere herein, and could include the expiration the validity of a certificate 122 with the first module public key 111 among many possible reasons. Although server 105 is illustrated as processing the module instruction 502 at steps 1103, an application server 171 or another server associated with M2M service provider 108 or module provider 109 could send a signal to server 105 for module 101 to derive new keys, and server 105 could then send module 101 a module instruction 502 to derive new keys at step 1103. In an exemplary embodiment, any module instructions 502 originated outside server 105 in a system 100 illustrated in FIG. 1 may preferably be sent to server 105 before sending to module 101, since other servers besides server 105 in a system 100 illustrated in FIG. 1 would not normally be able to send a packet to module 101 due to the presence of firewall 104. In accordance with an exemplary preferred embodiment, (i) module 101 may only receive a module instruction 502 from a server 105, where server 105 had previously received a message 208, (ii) before module 101 receives the module instruction 502. Further, module 101 may only receive a module instruction 502 both (i) after sending a message 208 and (ii) before the expiration of a firewall port binding timeout value 117 after sending the message 208.

Server 105 can then use step 503 illustrated in FIG. 5a to encrypt (i) the module instruction 502 and (ii) the second parameters 126 in a server encrypted data 504, where the module instruction 502 comprises an instruction for module 101 to derive a new pair of keys. Server 105 can use a symmetric key 127 and a symmetric ciphering algorithm 141b to encrypt the module instruction 502 and second parameters 126. The symmetric key 127 used in step 503 illustrated in FIG. 11 could be processed using the first module public key 111, where server 105 had (i) verified the identity of module 101 using a module digital signature 405 using the first module public key 111, and then (ii) subse-

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quently sent or received the symmetric key 127 with module 101 after the module digital signature 405 was verified using the first module public key 111. Alternatively, server 105 could have sent the symmetric key 127 to module 101 in a response 209 using an asymmetric ciphering algorithm 141a and the first module public key 111. Although not illustrated in FIG. 11, in a different but related embodiment to FIG. 11, step 506 can be substituted for step 503, such that module instruction 502 and/or second parameters 126 are not encrypted but rather a server digital signature 506 processed for inclusion in a response at step 1104 below.

At step 1104, server 105 can then send a response 209 that includes the module instruction 502 and second parameters 126, where the module instruction 502 could be included in a server encrypted data 504. The response 209 could be formatted according to the exemplary response 209 illustrated in FIG. 6a, where the response 209 can include a module instruction 502 for the module 101 to derive a new key pair. The response 209 could be to (i) the second message 208 received at step 1101, or (ii) a subsequent message 208 received by server 105 after the second message 208 received in step 1101 and not shown in FIG. 11. The response 209 at step 1104 can also include a second set of parameters 126 and a security token 401. As contemplated herein, the terms "parameters" and "set of parameters" may be considered equivalent. If response 209 at step 1104 does not include a server encrypted data 504, then response 209 at step 1104 may preferably include a server digital signature 506.

The second set of parameters 126 at step 1104 could be related to the first set of parameters 126 at step 516 illustrated in FIG. 11, or may be different. As one example, a second set of parameters 126 could include a different expiration date or time-to-live value for a new module public key 111. The second set of parameters 126 could include a new elliptic curve name or values for a defining equation, including a new elliptic curve for a cryptographic algorithms 141 to be utilized by module 101. Thus, according to a preferred exemplary embodiment, a set of parameters 126 sent to a module in a response 209 can include values for an elliptic curve defining equation. In this manner, module 101 and server 105 can utilize an elliptic curve for an ECC algorithms 154 that is different than an ECC standard curve 138. For example, module 101 and server 105 may prefer to use an elliptic curve for ECC algorithms 154 that is different than defined curves in standards such the list of curve names in section 5.1.1 of IETF RFC 4492 entitled "Elliptic Curve Cryptography (ECC) Cipher Suites for Transport Layer Security (TLS)", and other related curves such as defined curves published by NIST.

One benefit of utilizing a non-standard elliptic curve (where the curve can be defined using a ECC parameters 137 in a parameters 126) is that security can be increased, since attempts to break encryption with standard elliptic curves could not be readily applied to non-standard elliptic curves used in an ECC algorithm 154 (i.e. rainbow tables and the like generated for one elliptic curve would not normally be applicable for a sufficiently different elliptic curve). In accordance with a preferred exemplary embodiment, at step 1104 the second set of parameters 126, which can include values for a defining equation and/or ECC parameters 137, can be sent to a module 101 in a response 209, where the parameters 126 are within a server encrypted data 504. The security of a system 100 can be increased by keeping confidential the elliptic curve used in an ECC algorithm 154. By sending ECC parameters 137 (possibly within the second set of parameters 126) in a server encrypted data 504 in a

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response 209, where ECC parameters 137 include values for a different elliptic curve for module 101 to utilize in a cryptographic algorithms, the security of a system 100 can be further increased since the underlying elliptic curves used with public and private keys can change over time.

Module 101 can receive the response 209 sent in step 1104 with the module instruction 502 instructing module 101 to derive a new key pair using the second set of parameters 126. Note the second set of parameters 126 could be omitted in the response 209 sent in step 1104 and in this case module 101 can use the first set of parameters from step 516 illustrated in FIG. 11. Module 101 can decrypt the server encrypted data 504 in a response 209 using a symmetric key 127 and/or the first module public key 111 sent in the first message at step 516 shown in FIG. 11. At step 515, module 101 can derive the new key pair using the second set of parameters 126. As depicted and described in connection with FIG. 5b, module 101 can use the second set of parameters 126, cryptographic algorithms 141, a key pair generation algorithms 141e, and a random number generator 128 to derive a second module public key 111 and a second module private key 112. The random number generator 128 could use input from a sensor 101f, radio 101z, and other hardware in order to input "noisy" data into a seed 129 used by random number generator 128, including using a module random seed file 139.

At step 1105, server 105 can receive the second module public key 111 from module 101 in a third message 208. The third message 208 could include a module identity 110, and the second module public key 112 could be authenticated by server 105 using step 517 depicted and described in connection with FIG. 5b above. Note that the third message 208 may also preferably include a module public key identity 111a, so that server 105 can properly track and identify which of a plurality of module public keys 111 may be used. Module public key identity 111a and module public key 111 could be received by server 105 in the form of a certificate 122, although the use of a certificate 122 is not required. Server 105 can authenticate the second module public key 111 at step 1105 using the first module public key 111 received in step 516 in FIG. 11. In one embodiment, the second module public key 111 could be authenticated by server 105, where the third message included a module digital signature 405 that module 101 processed using the first module private key 112. Server 105 could use the first module public key 111 and the first set of parameters 126 received in (or used with) step 516 of FIG. 11 to verify the module digital signature 405. In this manner, the second module public key 111 could be authenticated with or after step 1105 by server 105.

Upon receiving and authenticating the second module public key 111, server 105 can record the second module public key 111 in a module database 105k or store the key in other memory. After recording the second module public key 111, at step 1106 server 105 can receive a fourth message 208 that includes (i) a module identity, and (ii) a second module encrypted data 403, where the second module encrypted data 403 may be encrypted using the second module public key 111 received at step 1105. The second module encrypted data 403 could include second sensor data 604b or other data as well. Server 105 can decrypt the second module encrypted data 403 in order to extract the plaintext sensor data 604b, or other data for a server 105 or application 171i, including a server instruction 414 different than an "update" message.

At step 1107, server 105 can then send a second application message 701 to an application server 171 and/or

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application 171i, where the second application message could include the sensor data 604 received in step 1105 and the module identity 110. Server 105 can utilize a secure connection data transfer 802 to send the sensor data 604b and the module identity 110 received in step 1106. In an exemplary embodiment, the keys used for a secure connection data transfer 802 at step 1107 could be the same as used in the secure connection data transfer 802 at step 1102. In this manner, server 105 can support a change in public and private keys for module 101, while no change in public and private keys are required for application server 171 and/or application 171i. Further, application 171i may require a valid certificate 122 for server 105, while server 105 may not require a certificate 122 for each module 101. Although not illustrated in FIG. 11, steps 1106 and 1107 could repeat in sequence as server 105 continues to receive additional messages 208 from module 101 over time, and server 105 could continue to update application server 171 and/or application 171i by sending additional application messages 701. Application 171i can use the plurality of sensor data 604b received in FIG. 11 to update an application database 171k and information presented to a user 183 through a web portal 171j.

CONCLUSION

Various exemplary embodiments have been described above. Those skilled in the art will understand, however, that changes and modifications may be made to those examples without departing from the scope of the claims.

What is claimed is:

1. A mobile device comprising:

- (a) at least one processor; and
- (b) at least one computer-readable medium operatively connected to the at least one processor and having stored thereon instructions that, when executed by the at least one processor, cause the mobile device to perform a method of authentication with a wireless network, the method comprising:
 - (1) storing a server public key, a module identity, cryptographic algorithms, and a pre-shared secret key, wherein the module identity comprises a permanent identifier for the mobile device and the cryptographic algorithms includes a symmetric ciphering algorithm;
 - (2) deriving a module private key and a corresponding module public key using the cryptographic algorithms;
 - (3) deriving a symmetric ciphering key using (i) an elliptic curve integrated encryption scheme with the server public key and the module private key and (ii) an American National Standards Institute standard X-9.63 key derivation function;
 - (4) generating a module encrypted data using the symmetric ciphering key and the symmetric ciphering algorithm, wherein the module encrypted data includes the module identity;
 - (5) sending a message to a server for the wireless network, the message comprising the module encrypted data and the module public key, wherein the server mutually derives the symmetric ciphering key using at least the module public key, and wherein the wireless network selects the pre-shared secret key for the mobile device using the module identity; and
 - (6) authenticating with the wireless network using a message digest with the pre-shared secret key.

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2. The mobile device of claim 1, wherein the message further comprises a module identity string, the module identity string comprising a temporary identification for the mobile device.

3. The mobile device of claim 1, wherein the pre-shared secret key comprises a key K, wherein the mobile device and the wireless network mutually derive a response from (i) a random value and (ii) the key K, and wherein the mobile device receives the random value from the wireless network.

4. The mobile device of claim 1, wherein, in step (1), the pre-shared secret key is stored within a subscriber identity module card, the pre-shared secret key comprising a key K.

5. The mobile device of claim 1, wherein, in step (1), the pre-shared secret key is stored before the mobile device communicates with the wireless network.

6. The mobile device of claim 1, further comprising, in step (1), storing parameters for the cryptographic algorithms, the parameters comprising a standard curve for elliptic curve cryptography, and wherein, in step (2), the module public key and the module private key are derived using the standard curve.

7. The mobile device of claim 6, wherein, in step (5), the message further comprises the parameters for the cryptographic algorithms, and wherein the server mutually derives the symmetric ciphering key using at least the module public key and the parameters for the cryptographic algorithms.

8. The mobile device of claim 1, wherein the mobile device receives the pre-shared secret key via a wireless 802.11 connection to a web portal after a user for the mobile device submits a pre-shared secret key code for the mobile device to the web portal.

9. The mobile device of claim 1, further comprising, in step (2), deriving (i) the module private key from a random number generator and (ii) the module public key from a key pair generation algorithm, wherein the module private key comprises a random number.

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10. The mobile device of claim 9, wherein the random number generator is configured to generate the random number from a seed value, and wherein the seed value comprises data from at least one of a sensor and a radio for the mobile device.

11. The mobile device of claim 1, wherein, in step (1), the server public key is stored in a nonvolatile memory of the mobile device.

12. The mobile device of claim 1, wherein the server comprises a plurality of computers, wherein the plurality includes at least one sub-server and at least one database.

13. The mobile device of claim 1, wherein the server comprises at least one virtualized server operating on at least one computer.

14. The mobile device of claim 1, wherein the wireless network includes the server.

15. The mobile device of claim 1, wherein, in step (1), the module identity is stored in a read-only nonvolatile memory address, wherein the mobile device designates the read-only nonvolatile memory address as read-only for a time interval.

16. The mobile device of claim 1, wherein the wireless network comprises at least one base station communicating with a 3 GPP wireless technology.

17. The mobile device of claim 1, wherein the message comprises a single user datagram protocol packet.

18. The mobile device of claim 1, wherein the symmetric ciphering algorithm comprises an Advanced Encryption Standard algorithm and has a length of 128 bits.

19. The mobile device of claim 1, wherein the module identity comprises a number for an international mobile subscriber identity number.

20. The mobile device of claim 1, wherein the mobile device comprises a smartphone.

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