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SYSTEM AND METHOD TO IMPROVE CONNECTION RELIABILITY ON SMART METERS

Abstract

An advanced metering infrastructure includes a smart meter system with at least one sensor, a communication device, and a battery supply. The smart meter system is provided with algorithms and configuration to improve wireless connection reliability on the smart meter by providing more than one mobile operator configuration and more than one modem stacks for respective mobile network operators. When a mobile connection becomes unavailable, the system may automatically or manually change a mobile network operator and/or modem stack in hopes that communication quality and connection availability improves.

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Background/Summary

FIELD

[0001] The present disclosure generally relates to improving connection reliability on smart meters by providing plural mobile operator configurations and plural modem stacks for respective mobile network operators.

BACKGROUND

[0002] Smart meters are continuing to gain popularity with service providers, including for example utility providers such as power, gas, water, and sewage service providers. These smart meters, which are often battery powered by virtue of their deployment in remote locations or in locations without reliable or accessible power supply, are deployed and expected to operate for extended periods of time. Often, the life cycle of these smart meters is expected to be 15 to 20 years. Accordingly, it is important to optimize battery consumption to ensure that the meters operate for their intended life cycle.

[0003] In order to provide accurate, reliable, and timely utility usage, many smart meters are capable of wireless communication to enable the meter to connect to the Head-End System (HES) of a utility provider, and the like, and are configured to send information to this HES. The HES system in turn may use this information, which may include consumption information, to generate billing and analytics data.

[0004] Wireless communication technologies change over time, and the connection between the meter and the HES may become obsolete or the environmental changes, such as cell tower location, obstructions introduced during the meter life cycle, interference introduced from new sources, and the like, may cause the connection between the meter and the HES to become unstable or unusable. This results in inaccurate, incomplete, or unavailable consumption data which causes loss for the utility provider. Accordingly, there exists a need for smart meters to be provided with a more robust and adaptable wireless communications system compatible the unique requirements of a battery-powered, long lifecycle energy consumption requirements.

SUMMARY

[0005] The aforementioned aspects and other objectives can now be achieved as described herein.

[0006] In an embodiment, a smart meter system (**100**) comprises: a utility meter configured to measure real-time distribution of a resource and generate metrology data indicating a quantity of the resource consumed; a wireless communication device configured to establish a connection with one or more mobile networks based on one or more subscriber identity modules (SIMs), the wireless communication device comprising a transceiver capable of sending and receiving information via the one or more mobile networks and further comprising one or more configuration profiles; wherein, in response to a first condition being met, the wireless communication device switches from a first configuration profile to a second configuration profile; and wherein, in response to a second condition being met, the wireless communication device switches from a first mobile network to a second mobile network.

[0007] In an embodiment, a system further comprises wherein the switching from a first mobile network to a second mobile network corresponds with switching from a first SIM to a second SIM.

[0008] In an embodiment, a system further comprises wherein when the communication device has switched to the second SIM, the communication device is configured to change the one or more configuration profiles based on the second SIM.

[0009] In an embodiment, a system further comprises wherein, in response to a third condition, the communication device switches from a second SIM to a third SIM.

[0010] In an embodiment, a system further comprises wherein the smart meter system is further configured to measure and record a connection quality indicator, and wherein the first condition is met when the connection quality indicator satisfies a first threshold and one or more unused configuration profiles exist.

[0011] In an embodiment, a system further comprises wherein the second condition is met when the connection quality indicator satisfies a first threshold and no unused configuration profiles exist.

[0012] In an embodiment, a system further comprises wherein the one or more configuration profiles correspond to a communication standard confirming to one or more of Cat-M, NB-IoT, LTE-M, LPWAN, 5G-MMTC, 5G-RedCap, eRedCap, and feRedCap.

[0013] In an embodiment, a system further comprises wherein power saving profile conforms to one or more of an extended discontinuous reception (eDRX) and power saving mode (PSM) standards.

[0014] In an embodiment, a system further comprises wherein when the wireless communication device (**120**) switches in response to the first condition or the second condition, the wireless communication device is configured to perform a reset and to establish a connection based on the second configuration profile or second mobile network, respectively.

[0015] In an embodiment, an advanced metering system, comprises: a plurality of smart meter systems, each smart meter system comprising: a utility meter configured to measure real-time distribution of a resource and generate metrology data indicating a quantity of the resource consumed; a wireless communication device configured to establish a connection with one or more mobile networks based on one or more subscriber identity modules (SIMs), the wireless communication device comprising a transceiver capable of sending and receiving information via the one or more mobile networks and further comprising one or more configuration profiles; wherein, in response to a first condition being met, the wireless communication device switches from a first configuration profile to a second configuration profile; and wherein, in response to a second condition being met, the wireless communication device switches from a first mobile network to a second mobile network; and a head-end system (HES) configured to communicate with the plurality of smart meters via the one or more mobile networks.

[0016] In an embodiment, a system further comprises wherein the HES is further configured to transmit one or more command signals to one or more of the plurality of smart meters.

[0017] In an embodiment, a system further comprises wherein the one or more command signals corresponds causes the communication device of one or more smart meters to switch from the first configuration profile to the second configuration profile.

[0018] In an embodiment, a system further comprises wherein the one or more command signals corresponds causes the communication device of one or more smart meters to switch from the first SIM to the second SIM.

[0019] In an embodiment, a system further comprises wherein the plurality of smart meters are configured to transmit the information to the HES via the connection.

[0020] In an embodiment, a method operating a smart meter comprises: measuring, using a utility meter and sensor of the smart meter, a distribution of a resource; generating, using a processor, metrology data indicating a quantity of the resource consumed; establishing, using a wireless communication device, a connection with a first mobile network based on a first subscriber identity module (SIM) and a first configuration profile; determining, using a processor and storage of the wireless communication device, if the connection with the first mobile network has become unreliable, wherein the connection is determined to be unreliable if a first threshold is satisfied; switching, in response to the first threshold being satisfied, from a first configuration profile to a second configuration profile corresponding to the first SIM.

[0021] In an embodiment, a method further comprises determining, using the processor and storage, if the connection with the first mobile network using the first configuration profile has become unreliable, wherein the connection is determined to be unreliable if the first threshold is satisfied; determining, using the processor and storage, if the number of configuration profiles attempted equals the total number of configuration profiles and all configuration profiles have been used; switching, in response to the determination that the total number of configuration profiles have been used, from a first mobile network to a second mobile network.

Description

BRIEF DESCRIPTION OF THE FIGURES

[0022] The accompanying figures, in which like reference numerals refer to identical or functionally similar elements throughout the separate views and which are incorporated in and form a part of the specification, further illustrate the present invention and, together with the detailed description of the invention, serve to explain the principles of the present invention.

[0023] FIG. **1** illustrates an exemplary, high-level system overview for an advanced metering infrastructure (AMI) according to the present disclosure;

[0024] FIG. **2** illustrates a simplified overview of the mobile network operator (MNO) switching operation according to the present disclosure;

[0025] FIG. **3** illustrates a smart meter system according to the present disclosure;

[0026] FIG. **4** illustrates block diagram of the smart meter system of FIG. **3**;

[0027] FIG. **5** illustrates block diagram of the communication device of FIG. **4**;

[0028] FIG. **6** illustrates an exemplary, high-level process flow of the mobile network operator and modem stack switching as presently disclosed;

[0029] FIG. **7** illustrates an flow chart describing the process flow for switching mobile network operators and/or modem stacks;

[0030] FIG. **8** illustrates a flow chart describing the process flow for switching modem stacks for an exemplary system with two modem stacks; and

[0031] FIG. **9** illustrates a flow chart describing the process flow for switching mobile network operators for an exemplary system with two MNOs.

[0032] Unless otherwise indicated illustrations in the figures are not necessarily drawn to scale.

DETAILED DESCRIPTION

Background and Context

[0033] The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate one or more embodiments and are not intended to limit the scope thereof.

[0034] Subject matter will now be described more fully herein after with reference to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific example embodiments. Subject matter may, however, be embodied in a variety of different form and, therefore, covered or claimed subject matter is intended to be construed as not being limited to any example embodiments set forth herein, example embodiments are provided merely to be illustrative. Likewise, a reasonably broad scope for claimed or covered subject matter is intended. Among other issues, subject matter may be embodied as methods, devices, components, or systems. The followed detailed description is, therefore, not intended to be interpreted in a limiting sense.

[0035] Throughout the specification and claims, terms may have nuanced meanings suggested or implied in context beyond an explicitly stated meaning. Likewise, phrases such as “in one embodiment” or “in an example embodiment” and variations thereof as utilized herein may not necessarily refer to the same embodiment and the phrase “in another embodiment” or “in another example embodiment” and variations thereof as utilized herein may or may not necessarily refer to a different embodiment. It is intended, for example, that claimed subject matter include combinations of example embodiments in whole or in part.

[0036] In general, terminology may be understood, at least in part, from usage in context. For

example, terms such as “and,” “or,” or “and/or” as used herein may include a variety of meanings that may depend, at least in part, upon the context in which such terms are used. Generally, “or” if used to associate a list, such as A, B, or C, is intended to mean A, B, and C, here used in the inclusive sense, as well as A, B, or C, here used in the exclusive sense. In addition, the term “one or more” as used herein, depending at least in part upon context, may be used to describe any feature, structure, or characteristic in a singular sense or may be used to describe combinations of features, structures, or characteristics in a plural sense. Similarly, terms such as a “a,” “an,” or “the”, again, may be understood to convey a singular usage or to convey a plural usage, depending at least in part upon context. In addition, the term “based on” may be understood as not necessarily intended to convey an exclusive set of factors and may, instead, allow for existence of additional factors not necessarily expressly described, again, depending at least in part on context.
[0037] One having ordinary skill in the relevant art will readily recognize the subject matter disclosed herein can be practiced without one or more of the specific details or with other methods. In other instances, well-known structures or operations are not shown in detail to avoid obscuring certain aspects This disclosure is not limited by the illustrated ordering of acts or events, as some acts may occur in different orders and/or concurrently with other acts or events. Furthermore, not all illustrated acts or events are required to implement a methodology in accordance with the embodiments disclosed herein.
[0038] Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which the disclosed embodiments belong. Preferred methods, techniques, devices, and materials are described, although any methods, techniques, devices, or materials similar or equivalent to those described herein may be used in the practice or testing of the present invention.
[0039] Although claims have been included in this application to specific enumerated combinations of features, it should be understood the scope of the present disclosure also includes any novel feature or any novel combination of features disclosed herein.
[0040] References “an embodiment,” “example embodiment,” “various embodiments,” “some embodiments,” etc., may indicate that the embodiment(s) so described may include a particular feature, structure, or characteristic, but not every possible embodiment necessarily includes that particular feature, structure, or characteristic.
[0041] Headings provided are for convenience and are not to be taken as limiting the present disclosure in any way.
[0042] Each term utilized herein is to be given its broadest interpretation given the context in which that term is utilized.
Terminology
[0043] The following paragraphs provide context for terms found in the present disclosure (including the claims):
[0044] The transitional term “comprising”, which is synonymous with “including,” “containing,” or “characterized by,” is inclusive or open-ended and does not exclude additional, unrecited elements or method steps. See, e.g., *Mars Inc. v. H.J. Heinz Co.,* 377 F.3d 1369, 1376, 71 USPQ2d 1837, 1843 (Fed. Cir. 2004) (“[L]ike the term ‘comprising,’ the terms ‘containing’ and ‘mixture’ are open-ended.”). “Configured to” or “operable for” is used to connote structure by indicating that the mechanisms/units/components include structure that performs the task or tasks during operation. “Configured to” may include adapting a manufacturing process to fabricate components that are adapted to implement or perform one or more tasks.
[0045] “Based On.” As used herein, this term is used to describe factors that affect a determination without otherwise precluding other or additional factors that may affect that determination. More particularly, such a determination may be solely “based on” those factors or based, at least in part, on those factors.
[0046] All terms of example language (e.g., including, without limitation, “such as”, “like”, “for

example", "for instance", "similar to", etc.) are not exclusive of other examples and therefore mean "by way of example, and not limitation . . . ".
[0047] A description of an embodiment having components in communication with each other does not infer that all enumerated components are needed.
[0048] A commercial implementation in accordance with the scope and spirit of the present disclosure may be configured according to the needs of the particular application, whereby any function of the teachings related to any described embodiment of the present invention may be suitably changed by those skilled in the art.
[0049] The flowchart and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems and methods according to various embodiments. Functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.
[0050] Further, any sequence of steps that may be described does not necessarily indicate a condition that the steps be performed in that order. Some steps may be performed simultaneously.
[0051] The functionality and/or the features of a particular component may be alternatively embodied by one or more other devices that are not explicitly described as having such functionality/features. Also, various embodiments of the present invention need not include a device itself.
INTRODUCTION
[0052] The present disclosure generally relates to smart meters for measuring consumption of a commodity, such as water, electricity, natural gas, and the like, and transmitting the consumption data to the provider, such as a utility company or administrative management entity. The transmission of consumption data may occur over one of a variety of mobile network operator systems (e.g., cellular network providers) and the wireless communications system coupled with the smart meter may be configured to operate on more than one mobile network and operate with more than one radio technology available on each mobile network. The present disclosure further details how the smart meter may switch between plural mobile network operators and/or switch between plural radio technologies (e.g., modem stacks) for respective mobile networks.
[0053] FIG. **1** illustrates an exemplary advanced metering infrastructure (AMI) system including a smart meter **110** equipped with a wireless communication device **120** as described herein. The wireless communication device **120**, which may enable communication over cellular communications networks **130** using RF communication technologies conforming to 3G, 4G/LTE, 5G standards, and the like, allows for bi-directional exchange of data between the smart meter **110** and head-end system (HES)
[0054] Smart meters such as those discussed in the present disclosure may be deployed in remote or urban areas, and subject to changing environmental conditions including dynamically changing wireless communication environments which affect signal quality or wireless network availability. Such meters are also battery powered and expected to operate for 15 to 20 years or more. It is therefore important to optimize the battery consumption of these meters. In general, the smart meter may be configured to operate in a "deep-sleep" or similar low power mode for the majority of the time in order to save the battery. Some examples of lower power modes may include extended discontinuous reception (eDRX) mode or power saving mode (PSM), which enable devices to enter predefined sleep periods of up to about 40 minutes (for LTE-M) or nearly 3 hours (for NB-IoT). After this period, the device may "wake up" after the time has elapsed to check if there is data waiting from the network. In some examples, this waking time may be around 1 millisecond (ms) if the meter doesn't need to send or receive data. Accordingly, the eDRX-enabled devices are very power efficient.
[0055] However, smart meters are intended to have life cycles of 15-20 years and the environment surrounding the smart meter may undergo significant changes in this time. For example, new

building construction, new cell tower construction, removal of cell towers, changing wireless communications protocols, the introduction of new wireless communications systems near the smart meter, and other natural and man-made changes to the smart meter's environment, and the like, may all contribute to reduced connectivity between the smart meter and the wireless communications network(s). In some instances, the smart meter may become unable to communicate with the wireless network because of these changes. Since smart meters are expected to have life cycles spanning decades, and since it is not feasible to move the utility infrastructure in response to the changes, a system is needed which enables the smart meter to adapt to changing wireless communication environments in an efficient manner to maintain connectivity with the head-end system (HES).

[0056] FIG. **2** illustrates a simplified overview of the mobile network operator (MNO) switching operation for cellular communication equipped smart meters **110** of the present disclosure. As will be discussed herein, in addition to having the ability to switch between various mobile network operators **131** and **132**, the smart meter **110** and wireless communication device **120** may also enable switching between various RF communication technologies for respective MNOs. For example, in FIG. **2**, when the wireless communication device **120** is unable to connect to a first MNO **131**, the wireless communication device **120** may reconfigure itself to communicate with a second MNO **132**. Both the first MNO **131** and second MNO **132** are capable of communicating with the gateway server **150** which inter-connects the MNO's and the with an enterprise's head-end system (HES) **140**.

[0057] It is noted that although two mobile network operators **131**, **132** are illustrated in FIG. **2**, the present disclosure is not limited thereto and the wireless communication device **120** may be configurable to switch among three or more mobile network operators. Additionally, over-the-air processes such as remote SIM provisioning may enable the HES **140** to provide new or replace existing SIM profiles, and/or provide new or replace existing RF communication technologies, as needed to adjust which MNOs the wireless communication device **120** can communicate with.

[0058] FIG. **3** illustrates a system **100** with a smart meter **110**. Connected to the smart meter **110** is a utility communication device **120**. The communication device **120** attached to the smart meter **110**, communicates with a gas utility system (e.g., a head-end system (HES) **140**, see FIGS. **1** and **2**) positioned at end points of the system **100**. The HES **140** receives alerts in relation to the consumption data and status information from the smart meter **110** and can transmit command and control information the smart meter **110** and/or communication device **120** to change operation and configuration of the smart meter **110** and/or communication device **120**. The communication device **120** can be provided inside the smart meter **110** in one or more embodiments. In other embodiments, the communication device **120** can be positioned on the smart meter **110**. The communication device **120** can receive information on the smart meter **110** in relation to consumption data and status information via a physical connection (e.g, cable), and communicate that information to the gas utility system/HES. The communication device **120** also is configured to alert the gas utility system/HES of changes to consumption data and status information of the system **100** components.

[0059] FIG. **4** is a block diagram of the smart meter **110** of FIGS. **1-3**. A smart meter **110** of the present disclosure may comprise a processor **112** for executing instructions stored in storage **114**, which may include one or more of random-access memory (RAM), read-only memory (ROM), solid state device (SSD) storage, hard disc drive (HDD) storage, and the like. Storage **114** may contain algorithms and executable code for the processor **112** to execute in order to operate smart meter **110** components such as the sensor **116** and communication device **120**. Storage **114** may also store sensor data and other analytical data the smart meter **110** collects. Storage **114** may further temporarily store data to be transmitted to or received from the communication device **120**.

[0060] In some examples the sensor **116** may be a gas pressure or gas flow sensor that enables the processor **112** to monitor and record gas consumption or gas infrastructure conditions. In other examples the sensor **116** may be configured to measure and monitor electrical current, electrical voltage, water pressure, water flow, and the like, to enable measurement of consumption of electricity or water, respectively. The smart meter **110** may be configured with one or more sensors **116**, and plural sensors **116** may be of different types.

[0061] Smart meter **110** may also be provided with a battery **118**, such a non-rechargeable or rechargeable battery, to provide reliable power to the smart meter **110** and communication device **120**. If communication device **120** is provided external to the smart meter **110**, as illustrated in FIG. **3**, then a power cable or similar connection (not shown) may be provided to the communication device **120**. Battery **118** may be configured with enough energy storage to operate the smart meter **110** and communication device **120** for many years. In some examples the battery **118** is provided with enough stored energy to operate the smart meter **110** and communication device **120** for 1 years, 3 years, 5 years, 10 years, 15 years, 20 years, or longer. If battery **118** is a rechargeable battery, it may be recharged in various ways, such as via a photovoltaic cell (not shown) connected to the smart meter **120** or other renewable energy generator source (not shown).

[0062] As illustrated in FIG. **4** and discussed above, the smart meter **110** may also include a communication device **120**, such as a wireless communication device, which enables the smart meter **110** to register with and communicate over wireless networks including, for example, a cellular or GSM-compliant mobile network **130** such as 2G, 3G, LTE, 5G, and the like (see FIG. **1**). In some examples the communication device **120** may be included in the smart meter **110**, such as provided on the same card, same board, or provided within the same enclosure as the other components of meter **110**. In other examples, the communication device **120** may be provided external to the smart meter **110** but in electrical communication therewith. For example, communication device **120** may be attached to the smart meter **110** and connected with a cable (not shown) allowing for data transfer between the smart meter **110** and the communication device **120**.

[0063] FIG. **5** is a block diagram of the communication device **120** discussed above with respect to FIGS. **1-4**. Communication device **120** may include a processor **122** for operating the communication device **120** based on algorithms and executable code stored in storage **124**. Communication device **120** may also include mobile network operator (MNO) profiles, stored in storage **124**, which correlate with one or more Subscriber Identity Modules (SIMs) **135** or one or more programmable embedded SIMs (eSIMs) **136**. It is noted that although illustrated as having both physical, removable SIMs **135** and eSIMs **136**, the wireless communication device **120** may have only physical SIMs **135** or eSIMs **136** without departing from the scope of the present disclosure. Similarly, storage **124** may also store various RF technology configurations for respective MNOs, such as modem stack configurations based on LTE-M, Cat-M. NB-IoT, low-power wide area network (LPWAN), mobile IoT, 5G-MMTC, 5G-RedCap. eRedCap, feRedCap and similar RF communication technologies which vary among mobile network operators. Processor **122** may be configured to program or reprogram eSIMs **136** based on the MNO profiles in storage **124**, and MNO profiles may be selected, provided, or updated via over-the-air commands received via transceiver **126**. That is, in some examples the MNO profiles, and their respective eSIM configurations, may be transmitted to the communication device **120** by a central control unit, such as a Head End System (HES) and the like.

[0064] Communication device storage **124** may include one or more of random-access memory (RAM), read-only memory (ROM), solid state device (SSD) storage, hard disc drive (HDD) storage, and the like. Storage **124** may also contain algorithms and executable code for the processor **122** to execute to control operation of the transceiver **126** and other communication device **120** operation (e.g., remote SIM provisioning (RSP). SIM and eSIM selection, power reset, power down, power mode change, and the like). A portion of storage **124** may operate as cache storage to retain performance records such as network (NW) registration status, reference signal received quality (RSRQ) or other connection quality metrics, call success rate, elapsed time since last successful communication, and the like. It is noted that although discussed herein as being stored in cache, performance records may be stored in other types of storage discussed above such as registers. RAM, ROM, SSDs, HDDs, and the like. Cache storage may be a dedicated portion of physical storage or may be stored as part of storage for logical operations used by the processor **112** and software executed by the processor **112**. Communication device storage **124** may also temporarily store data transmitted or received via the transceiver **126**, and also may store data for transmission to or received from smart meter **110**. Data transmission between the smart meter **110** and communication device **120** may be exchanged via a via wired connection (e.g., a cable, optical interlink, ethernet, and the like) or wireless connection (e.g., NFC, Bluetooth (BT), BT low energy (BTLE), WiFi/IEEE 802.11, and the like). A wired connection (not shown) between communication device **120** and meter **110** may be provided via a combined cable connection for providing power from the battery **118** in the meter **110**, or may be provided in a dedicated data transmission cable.

[0065] As illustrated in FIG. **5**, in some examples the transceiver **126** may include a wireless transmitter module **128** and a wireless receiver module **129**. The transmitter and receiver modules **128**, **129** may be provided separately or integrated on a transceiver module.

[0066] FIG. **6** illustrates the general flow of the mobile network operator (MNO) profile switching and RF technology switching operations of the present disclosure. The smart meter **110** and communication device **120** as disclosed herein automatically switches between mobile network operator profiles, and automatically switches between RF technologies corresponding to those MNO profiles. By way of example, and without limitation, a general flow using two MNO profiles is illustrated. In a first configuration, the communication device **120**, and therefore the smart meter **110**, is configured to communicate with a head-end system (HES), or other reporting and control system, using a first MNO **202**. While using first MNO **202**, the communication device **120** may use a first modem stack **210**, such as an RF technology confirming to the Cat-M standard, to transmit and receive data while requiring less power consumption compared with traditional mobile communication protocols.

[0067] If communication with first MNO **202** using modem stack **210** becomes inconsistent, unreliable, or unavailable, the communication device **120** may automatically, or manually in response to a command from HES or other control system, switch to another modem stack **212**A, such as RF technology conforming to the Narrowband Internet of Things (NB-IoT) standard, and attempt registration with first MNO **202**. If communication with first MNO **202** with modem stack **212**A is unavailable or becomes inconsistent, unreliable, or unavailable, the communication device **120** may automatically, or manually, switch to another modem stack **212**B, such as RF technology conforming to the Extended Coverage GSM Internet of Things (EC-GSM-IoT) standard, and again attempt registration with first MNO **202**. If once again the registration with first MNO **202** becomes unreliable or unavailable, the communication device **120** may select an additional modem stack **212***n*, if available. It is noted that n represents any number of standardized modem stack configurations available and compatible with communications device **120**.

[0068] If no additional modem stacks **212***n* are available for first MNO **202**, then communications device **120** may automatically or manually switch to a second MNO **204**A. The communications device will then progress through modem stacks **220**, **222**A, **222**B, **222***n* as discussed above with respect to first MNO **202**. If no additional modem stacks **222***n* are available for second MNO **204**A, then communications device **120** may automatically or manually switch to a third MNO **204**B and progress through modem stacks **220**, **222**A, **222**B, **222***n* as discussed above with respect to first MNO **202** and second MNO **204**A. If no additional modem stacks **222***n* are available for third MNO **204**B, then communications device **120** may automatically or manually switch to an nth MNO **204***n* and progress through modem stacks **220**, **222**A, **222**B, **222***n* as discussed above with respect to first MNO **202**C, second MNO **204**A, and third MNO **204**B. If no additional MNOs are available, the communications device may power down or cycle back through first MNO **202** to repeat the process flow discussed above.

[0069] Accordingly, communications device **120** may utilize multiple MNO profiles **202**, **204**A-**204***n* and corresponding modem stacks **210**, **212**A-**212***n*, **220**, **222**A-**222***n* for the MNO profiles to attempt to remain in contact with the head-end system or other central control and reporting system. If during the life cycle of the smart meter **110** the communications environment changes, due to cell tower construction, removal, new building construction, and the like, the smart meter **110** is configured to cycle through various mobile network operators and various modem stacks for the operators to regain and improve connectivity with the HES.

[0070] It is noted that Cat-M is an RF technology standard categorized under LTE-M (aka. LTE-MTC), and includes several subtypes such as LC-LTE, LC-MTCe, LTE-Cat 0, Cat-M1, Cat-M2. For simplicity, the present disclosure refers to these standards more broadly as Cat-M, but the disclosure is consistent the other subtypes of LTE-M. Similarly, NB-IoT and EC-GSM-IoT are discussed as other modem stack examples, but the present disclosure is not limited to these and a person of ordinary skill in the art would recognize that other IoT and low-power communications standards would be consistent with the presently disclosed smart meter system.

[0071] It is noted, however, that power-hungry communications standards such as WiFi, WiMAX, and the like, which are not optimized for power-efficient or low-power devices with long life cycles, such as the disclosed smart meter **110** system, would not be consistent with the present disclosure. The use of WiFi and other similar technologies for transfer and reception of data with the smart meter **110** system would not allow for the multi-year long life cycles necessary in advanced metering infrastructures such as those disclosed herein. Additionally, in addition to being power hungry, the range of WiFi-based communications protocols is significantly smaller than the communications range of mobile networks conforming to low-power 3GPP or GSM standards such as those discussed above. As such, the reduced range would not enable the construction and operation of effective, efficient advanced metering infrastructures such as those using the smart meter system disclosed herein.

[0072] FIG. **7** illustrates an exemplary flow chart **700** describing the process of switching operator profiles and/or modem stack RF technologies as discussed above. Upon initiation, at step **702** the system **100** reads from storage, (e.g., storage **114** or **124**) a Stack Switching Performed (SSP) flag and Operator Switching (OS) flag. In step **702** a Stack Counter value and Operator Counter value is also read from storage. Stack Switching Performed SSP flag may in some examples be a True/False flag indicating if a modem stack switching operation has been performed and/or no additional modem stacks are available for the selected mobile network operator. Operator Switching (OS) flag may be a True/False flag indicating if switching of mobile network operators is desired.

[0073] Stack Counter (SC) may be a value representing a particular modem stack, with different modem stacks represented by different SC values. For example and without limitation, an SC value of 1 may indicate the use of a Cat-M modem stack. An SC value of 2 may indicate the use of an NB-IoT modem stack. Accordingly, a value SC.sub.max, which may be 3, 4, 5, 10, or more, represents the total number of modem stacks available. When SC.sub.max is exceeded, then no additional modem stacks are available for that mobile network operator. Similarly, Operator Counter (OC) may be a value representing a particular mobile network operator (MNO), with different MNOs represented by different OC values. For example and without limitation, an OC value of 1 may indicate the use of a first mobile network operator (e.g., Verizon). An SC value of 2 may indicate the use of second mobile network operator (e.g., AT&T). Accordingly, a value OC.sub.max, which may be 3, 4, 5, 10, or more, represents the total number of mobile network operators available. When OC.sub.max is exceeded, then no additional mobile networks are available for use by the system **100**.

[0074] Returning to step **702**, once the SSP flag, the OS flag, the SC value, and the OC value are read, the system proceeds to step **703**. In step **703**, the system determines if the connection is unreliable. Several factors can cause the connection to be deemed unreliable. In some examples, performance records such as network (NW) registration ability, reference signal received quality

(RSRQ) or other connection quality metrics, call success rate, elapsed time since last successful communication, and the like, may indicate if a connection is unreliable. The term “unreliable” in step **703** is comprises several levels of low-quality connections including insufficient bandwidth connections, insufficient connection durations to allow data transfer, a low percentage of successful network registrations, and in extreme cases an unavailable connection indicated by repeated MNO registration failures. In one non-limiting example, if a network registration success rate is less than 40%, or an average RSRQ is less than-18 dB, or communication has been unavailable for a period of time such as two days, then the connection may be deemed unreliable and necessitate MNO and/or modem stack switching.

[0075] At step **703**, if a connection is not deemed unreliable or a manual command from the HES has not been received (NO at step **703**), then the MNO and modem stack switching system proceeds to step **750** and ends. Operation of system **100** and communication device **120** proceeds with the presently-configured, reliable MNO connection and modem stack. If at step **703** the connection is deemed unreliable OR a manual command has been received from the HES (YES at step **703**), then the system proceeds to step **704** to begin MNO and/or modem stack switching.

[0076] In step **704**, if the SSP flag is True or the OS flag is True, the system proceeds to step **710** to begin switching the mobile network operator (MNO) according to the Operator Count (OC) value. As discussed above, OC values may correspond to particular MNOs, and thus a different OC value represents the use of another MNO. The MNO may be switched by changing the communication device **120** to use a SIM card or eSIM profile corresponding to the MNO corresponding to the OC value. The system then proceeds to step **712** wherein the OC value is incremented. In some examples the OC value may be incremented by 1, so an OC value may for example change from 1 to 2, 2 to 3, 3 to 4, etc. At step **714** the system checks to see if the OC value incremented in step **712** is greater than OC.sub.max, which represents the total number of MNOs available in the system. If the incremented OC value is greater than OC.sub.max, then system proceeds to step **716** to reset the OC value to 1, set the SSP flag to False, and set the OS flag to False. If, in step **714**, OC value is less than or equal to OC.sub.max, then the system proceeds to step **730** which returns flow back to step **703**.

[0077] Referring again to step **704**, if neither the SSP flag nor the OS flag are True, then the system proceeds to step **720**, wherein the system switches the modem stack according to the Stack Counter (SC) value.

[0078] As discussed above, SC values may correspond to particular modem stacks, and thus a different SC value represents the use of another modem stack. The modem stack may be switched by changing the communication device **120** to use different RF communication technology, which may differ slightly based on the MNO represented by an OC value since even with the same modem stack technology an MNO may have specific configurations. For example, an SC value of 1 may indicate using a Cat-M modem stack, while an SC value of 2 may indicate using an NB-IoT modem stack. Once the modem stack is switched in step **720**, the system then proceeds to step **722** wherein the SC value is incremented. In some examples the SC value may be incremented by 1, so an SC value may for example change from 1 to 2, 2 to 3, 3 to 4, etc. At step **724** the system checks to see if the SC value incremented in step **722** is greater than SC.sub.max, which represents the total number of modem stacks available in the system or available for the MNO corresponding to the OC value. If the incremented SC value is greater than SC.sub.max, then system proceeds to step **726** to reset the SC value to 1, set the SSP flag to True, and set the OS flag to True. If, in step **724**, SC value is less than or equal to SC.sub.max, then the system proceeds to step **730** which returns flow back to step **703**.

[0079] As discussed above with respect to FIG. **6**, which a high-level process flow overview corresponding to the process flow chart **700**, the modem stack and MNO switching operations may be performed automatically upon determination that a connection is unreliable (FIG. **7**, step **703**). However, if control center or head-end system (HES) would like the system **100** to switch MNOs or modem stacks manually, the HES can send a manual command to the system **100**. For example, if the HES wants the system to change MNOs, the HES can send a manual command to change SSP flag to True and OS flag to True. Similarly, if an HES would like the system **100** to switch modem stacks manually, the HES can send a manual command to set OS flag to False and SSP flag to True. Based on this manual command, system flow will proceed as desired by the HES as illustrated in flow chart **700**.

[0080] FIG. **8** illustrates a flowchart **800** describing a modem stack switching process flow for an exemplary system **100** configured with, for example, two modem stacks. After initiating, in step **802** the system reads network registration status, call status, and RSRQ from the cache. In step **804** the system determines if network registration or call failure has occurred. If network registration or call failure has not occurred (NO at step **804**), then the system proceeds to step **810** to determine if a manual command to switch modem stacks has been received from the head-end system (HES) or other control center. If a manual command has not been received (NO in step **810**), then the system proceeds to step **812** to operate in extended discontinuous reception (eDRX) mode.

[0081] Returning to step **804**, if a network registration failure or call failure has occurred (YES at step **804**), then the system proceeds to step **820** to determine if a network registration success rate percentage is below a threshold X %; if the average RSRQ is below a threshold Y decibels (dB); or if the elapsed time since the last successful communication is greater than a threshold T. In one non-limiting example, the threshold X is set to 40%, the threshold Y is set to −18 dB, and/or the threshold Tis set to 2 days (or equivalent hours, minutes, or seconds).

[0082] If in step **820** one of the thresholds is not satisfied (NO in step **820**), the system may proceed to step **830** to power down the communication device **120** and wait for the next scheduled network registration attempt in order to reduce battery consumption when communications have been sufficiently unreliable or communication has been unavailable for an extended period of time. If in step **820** one of the thresholds X, Y, or T are met (YES at step **820**), then the system proceeds to step **822**.

[0083] In step **822**, the system determines if the modem is configured with the Cat-M modem stack. If the modem is configured with the Cat-M modem stack, then the system proceeds to step **826** to switch the modem stack to NB-IoT. Once switched, the system proceeds to step **828** to clear NW Reg Stat, Call Status, and RSRQ cache. The modem is also reset so that the new modem stack can be initiated. Flow proceeds to step **850** with a return to step **804**. It is also noted that, as discussed above, if a HES or other central control system administrator wants to manually switch the modem stack (YES in Step **810**), the system will proceed to step **822** to proceed as above with switching modem stacks.

[0084] Returning to step **822**, if the system determines that the modem is not configured with a Cat-M modem stack (NO in step **822**), then the system proceeds to step **824** to switch modem stacks to Cat-M. Once the modem stack is switched in step **824**, flow proceeds to step **828** to clear NW Reg Stat, Call Status, and RSRQ cache. The modem is also reset so that the new modem stack can be initiated. Flow proceeds to step **850** with a return to step **804**.

[0085] FIG. **9** illustrates a flowchart **900** detailing a mobile network operator (MNO or “operator”) switching process exemplary system **100** configured with, for example, two MNOs. After initiating, in step **902** the system reads network registration status, call status, and RSRQ from the cache. In step **904** the system determines if network registration or call failure has occurred. If network registration or call failure has not occurred (NO at step **904**), then the system proceeds to step **910** to determine if a manual command to switch Operators has been received from the head-end system (HES) or other control center. If a manual command has not been received (NO in step **810**), then the system proceeds to step **912** to operate in extended discontinuous reception (eDRX) mode.

[0086] Returning to step **904**, if a network registration of call failure has occurred (YES at step **904**), then the system proceeds to step **905** to determine if the system is allowed to perform an

Mobile Network Operator switch. If a MNO switch is not allowed (NO in step **905**), the system proceeds to step **930** to power down the communication device **120** and wait for the next scheduled network registration attempt. For example and without limitation, an example of when an MNO switch is not allowed would be when a single SIM is provided, in which case only configuration profiles can be switched. If a MNO switch is allowed (YES in step **905**), the system proceeds to step **920** to determine if a network registration success rate percentage is below a threshold X %; if the average RSRQ is below a threshold Y decibels (dB); or if the elapsed time since the last successful communication is greater than a threshold T. In one non-limiting example, the threshold X is set to 40%, the threshold Y is set to-18 dB, and/or the threshold Tis set to 2 days (or equivalent hours, minutes, or seconds).
[0087] If in step **920** one of the thresholds is not satisfied (NO in step **920**), the system may proceed to step **930** to power down the communication device **120** and wait for the next scheduled network registration attempt in order to reduce battery consumption when communications have been sufficiently unreliable or communication has been unavailable for an extended period of time. If in step **920** one of the thresholds X, Y, or T are met (YES at step **920**), then the system proceeds to step **922**.
[0088] In step **922**, the system proceeds with switching from a first MNO to a second MNO. As previously discussed, the system may include more than two MNOs and this example is provided with two MNOs to describe exemplary, non-limiting functionality. Once the MNO is switched, the system proceeds to step **928** to clear NW Reg Stat, Call Status, and RSRQ cache. The modem is also reset so that the new startup procedures for the new MNO can be initiated. Flow proceeds to step **950** with a return to step **904**.
[0089] It is also noted that, as discussed above, if a HES or other central control system administrator wants to manually switch the modem stack (YES in Step **910**), the system will proceed to step **911** to determine if an Operator switch is allowed. If an Operator switch is allowed (YES in step **911**), then the system proceeds to step **922** to switch MNOs. If an operator switch is not allowed (NO in step **911**), then the proceeds to step **912** to operate in extended discontinuous reception (eDRX) mode.
CONCLUSION
[0090] All references, including granted patents and patent application publications, referred herein are incorporated herein by reference in their entirety.
[0091] All the features disclosed in this specification, including any accompanying abstract and drawings, may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.
[0092] Various aspects of the invention have been described above by way of illustration, and the specific embodiments disclosed are not intended to limit the invention to the particular forms disclosed. The particular implementation of the system provided thereof may vary depending upon the particular context or application. The invention is thus to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the following claims. It is to be further understood that not all of the disclosed embodiments in the foregoing specification will necessarily satisfy or achieve each of the objects, advantages, or improvements described in the foregoing specification.
[0093] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed.

Claims

1. A smart meter system comprising: a utility meter configured to measure real-time distribution of a resource and generate metrology data indicating a quantity of the resource consumed; a wireless communication device configured to establish a connection with one or more mobile networks based on one or more subscriber identity modules (SIMs) or SIM with multiple mobile operator profile, the wireless communication device comprising a transceiver capable of sending and receiving information via the one or more mobile networks and further comprising one or more radio access technology (RAT) configuration; wherein, in response to a first condition being met, the wireless communication device switches from a first RAT configuration to a second RAT configuration; and wherein, in response to a second condition being met, the wireless communication device switches from a first mobile network operator to a second mobile network operator.
2. The system of claim 1, wherein the switching from a first mobile network operator to a second mobile network operator corresponds with switching from a first SIM to a second SIM.
3. The system of claim 2, wherein when the communication device has switched to the second SIM, the communication device is configured to change the one or more RAT configuration based on the second SIM.
4. The system of claim 3, wherein, in response to a third condition, the communication device switches from a second SIM to a third SIM.
5. The system of claim 1, wherein the smart meter system is further configured to measure and record a connection quality indicator, and wherein the first condition is met when the connection quality indicator satisfies a first threshold and one or more unused RAT configuration exist.
6. The system of claim 5, wherein the second condition is met when the connection quality indicator satisfies a first threshold and no unused RAT configuration exist.
7. The system of claim 5, wherein the first threshold is one or more of a call success rate, average reference signal received quality (RSRQ), the registration/attach time, and an elapsed time period of last successful call.
8. The system of claim 1, wherein the resource is one or more of natural gas, electricity, heat, or water and the metrology data is a measure of the quantity of the resource consumed at a first location over a first time interval.
9. The system of claim 1, wherein the one or more RAT configuration correspond to a communication standard confirming to one or more of Cat-M, NB-IoT, LTE-M, LPWAN, 5G-MMTC, 5G-RedCap, eRedCap, and feRedCap.
10. The system of claim 9, wherein the one or more RAT configuration is configured according to the one or more SIMs used in establishing the connection.
11. The system of claim 1, wherein the smart meter system further comprises a battery and wherein the wireless communication device is configured to use a power saving profile corresponding to the one or more SIMs or the one or more RAT configuration.
12. The system of claim 1, wherein power saving profile conforms to one or more of an extended discontinuous reception (eDRX) and power saving mode (PSM) standards.
13. The system of claim 1, wherein when the wireless communication device switches in response to the first condition or the second condition, the wireless communication device is configured to perform a reset and to establish a connection based on the second RAT configuration or second mobile network operator, respectively.
14. An advanced metering system, comprising: a plurality of smart meter systems, each smart meter system comprising: a utility meter configured to measure real-time distribution of a resource and generate metrology data indicating a quantity of the resource consumed; a wireless communication device configured to establish a connection with one or more mobile networks based on one or more subscriber identity modules (SIMs) or SIM with multiple mobile operator profile, the wireless communication device comprising a transceiver capable of sending and receiving

receiving information via the one or more mobile networks and further comprising one or more RAT configuration; wherein, in response to a first condition being met, the wireless communication device switches from a first RAT configuration to a second RAT configuration; and wherein, in response to a second condition being met, the wireless communication device switches from a first mobile network operator to a second mobile network operator; and a head-end system (HES) configured to communicate with the plurality of smart meters via the one or more mobile networks.

15. The system of claim 14, wherein the HES is further configured to transmit one or more command signals to one or more of the plurality of smart meters.

16. The system of claim 15, wherein the one or more command signals corresponds causes the communication device of one or more smart meters to switch from the first RAT configuration to the second RAT configuration.

17. The system of claim 15, wherein the one or more command signals corresponds causes the communication device of one or more smart meters to switch from the first SIM to the second SIM or one mobile operator profile to another mobile operator profile.

18. The system of claim 15, wherein the plurality of smart meters are configured to transmit the information to the HES via the connection.

19. A method operating a smart meter, the method comprising: measuring, using a utility meter and sensor of the smart meter, a distribution of a resource; generating, using a processor, metrology data indicating a quantity of the resource consumed; establishing, using a wireless communication device, a connection with a first mobile network based on a first subscriber identity module (SIM) and a first RAT configuration; determining, using a processor and storage of the wireless communication device, if the connection with the first mobile network has become unreliable, wherein the connection is determined to be unreliable if a first threshold is satisfied; and switching, in response to the first threshold being satisfied, from a first RAT configuration to a second RAT configuration corresponding to the first SIM.

20. The method of claim 19, further comprising: determining, using the processor and storage, if the connection with the first mobile network using the first RAT configuration has become unreliable, wherein the connection is determined to be unreliable if the first threshold is satisfied; determining, using the processor and storage, if the number of configuration profiles attempted equals the total number of RAT configuration and all RAT configuration have been used; and switching, in response to the determination that the total number of RAT configuration have been used, from a first mobile network operator to a second mobile network operator.