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(54) **METHOD FOR UPGRADING RFID READERS IN SITU**

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G06K 7/10	(2006.01)

(Continued)

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CPC ***G06K 7/10227*** (2013.01); ***G06K 7/0008*** (2013.01); ***G06K 7/10009*** (2013.01); ***G06K 7/10287*** (2013.01); ***G07C 9/00007*** (2013.01)

(58) **Field of Classification Search**
CPC G06K 7/10227; G06K 7/0008; G06K 7/10009; G06K 7/10287; G06K 7/10356; G06K 7/10297; G06K 7/10316; G06K 17/0022; G06K 2017/007; G06K 7/10; G07C 9/00007; G05B 19/00; G06F 19/328

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,952,935	A	9/1999	Mejia et al.	
6,903,656	B1 *	6/2005	Lee	340/572.1

(Continued)

FOREIGN PATENT DOCUMENTS

EP	2157526	2/2010
WO	WO 2007/028634	3/2007

(Continued)

OTHER PUBLICATIONS

Extended Search Report for European Patent Application No. 12757113.1, dated Aug. 28, 2014 6 pages.

(Continued)

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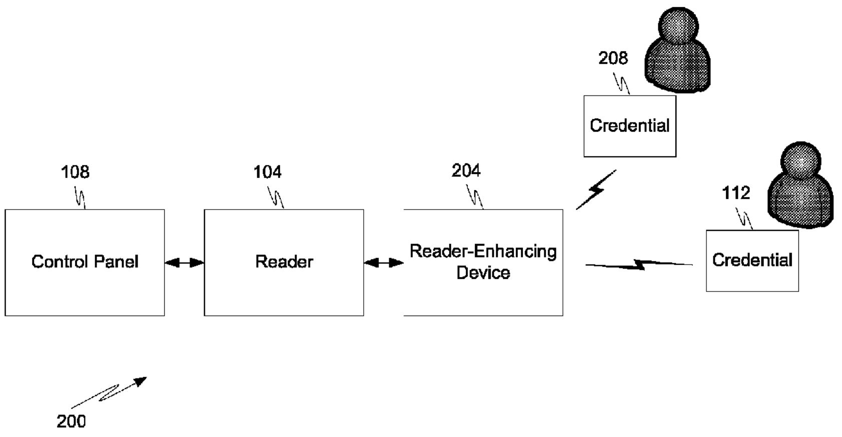
(57) **ABSTRACT**

A reader-enhancing device is proposed which enables an in situ upgrade of readers having limited processing capabilities. The reader-enhancing device includes an emulation module that is capable of generating an output which emulates a first type of credential when the reader-enhancing device receives an input that is not in a format used by the first type of credential. The output generated by the emulation module enables the reader to respond to the input even though the input is not in a format natively supported by the reader.

22 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

G06K 7/00	(2006.01)
G07C 9/00	(2006.01)

(58) **Field of Classification Search**

USPC 340/5.61

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,253,717	B2 *	8/2007	Armstrong et al.	340/10.2
7,392,943	B2	7/2008	Rietveld	
7,407,110	B2	8/2008	Davis et al.	
7,439,860	B2 *	10/2008	Andresky	340/572.1
7,439,862	B2	10/2008	Quan	
7,571,863	B2 *	8/2009	Lauper	235/492
7,592,898	B1 *	9/2009	Ovard et al.	340/10.4
7,690,579	B2 *	4/2010	Adams et al.	235/492
7,701,348	B2	4/2010	Kim	
7,782,209	B2	8/2010	Lowe et al.	
8,183,980	B2	5/2012	Davis et al.	
8,281,994	B1 *	10/2012	Wass et al.	235/385
2004/0065734	A1 *	4/2004	Piikivi	235/451
2004/0094625	A1	5/2004	Klosa et al.	
2004/0196143	A1 *	10/2004	Crump et al.	340/10.1
2004/0221151	A1 *	11/2004	Kajita	713/2
2006/0226969	A1 *	10/2006	Bandy	340/505
2006/0280149	A1 *	12/2006	Kuhl et al.	370/338
2007/0057057	A1	3/2007	Andresky et al.	
2007/0080806	A1 *	4/2007	Lax et al.	340/572.1
2007/0174907	A1	7/2007	Davis	
2008/0001746	A1 *	1/2008	Childress et al.	340/572.1
2008/0143519	A1 *	6/2008	Piotrowski	340/540
2008/0157968	A1 *	7/2008	Cunningham et al.	340/572.1
2008/0234999	A1 *	9/2008	Cohen et al.	703/26
2008/0235000	A1 *	9/2008	Cohen et al.	703/26
2008/0235711	A1 *	9/2008	Cohen et al.	719/318
2009/0009296	A1 *	1/2009	Shafer	340/10.1
2009/0166421	A1	7/2009	Finn	
2009/0184826	A1 *	7/2009	Kim	340/572.4
2010/0026458	A1 *	2/2010	Samdahl et al.	340/10.1
2010/0034375	A1	2/2010	Davis et al.	
2011/0143661	A1 *	6/2011	Hartwig et al.	455/41.1
2012/0066643	A1 *	3/2012	McRae	715/810
2012/0147798	A1 *	6/2012	Miller et al.	370/310

FOREIGN PATENT DOCUMENTS

WO	WO 2008/017889	2/2008
WO	WO 2009/008861	1/2009
WO	WO 2012036567 A1 *	3/2012

OTHER PUBLICATIONS

Davis "Migration Strategies (With an Emphasis on Moving from 125 kHz Prox to 13.56 MHz Contactless Smart Card Technology)," NIST Workshop on Storage & Processor Card-Based Technologies, Jul. 8, 2003, 28 pages.

International Search Report and Written Opinion for International (PCT) Patent Application No. PCT/US2012/029371, mailed Jun. 12, 2012 12 pages.

International Preliminary Report on Patentability for International (PCT) Patent Application No. PCT/US2012/029371, mailed Oct. 31, 2013 11 pages.

* cited by examiner

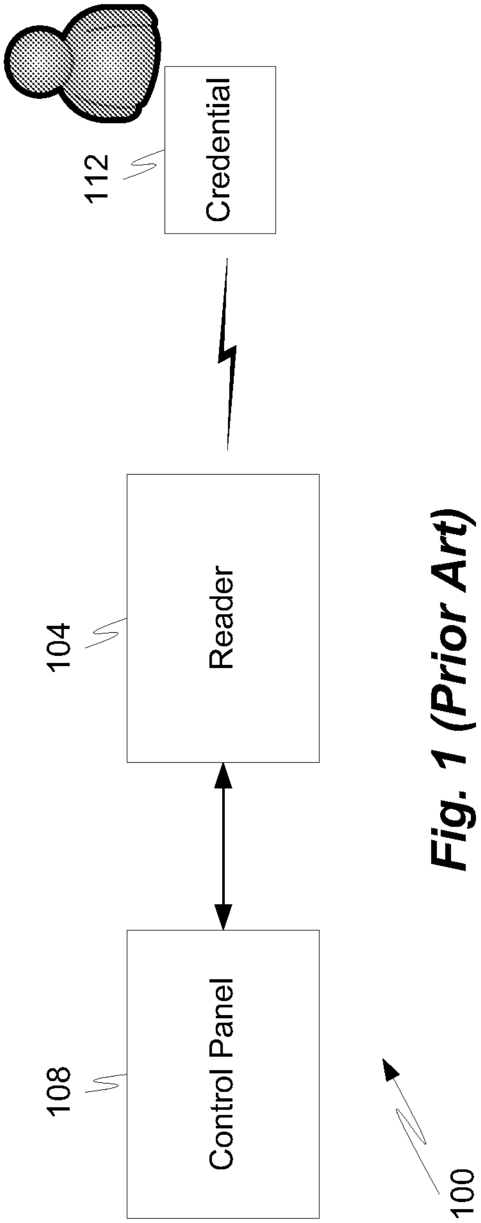


Fig. 1 (Prior Art)

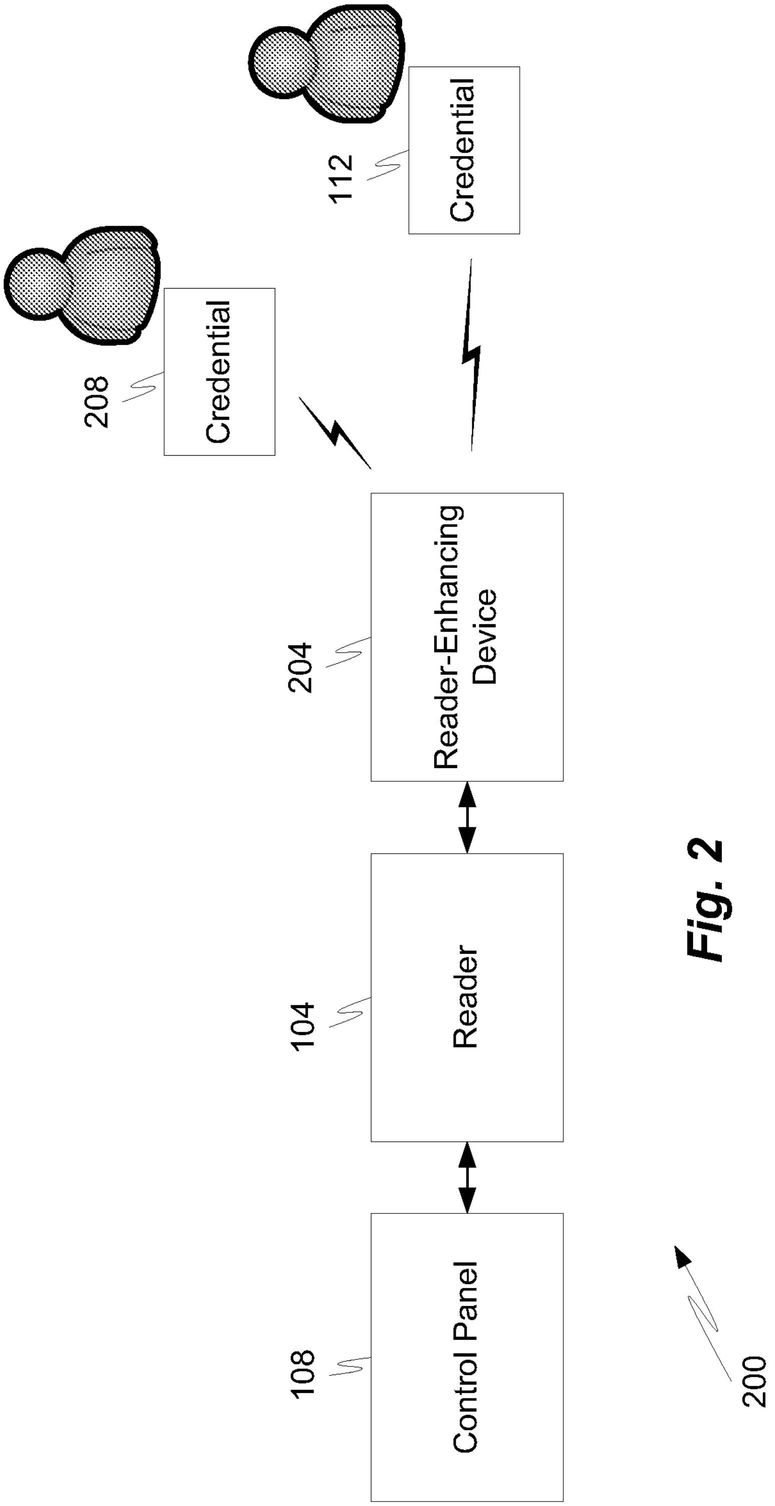

Credential
112
Credential
208
Reader-Enhancing Device
204
Reader
104
Control Panel
108
200

Fig. 2

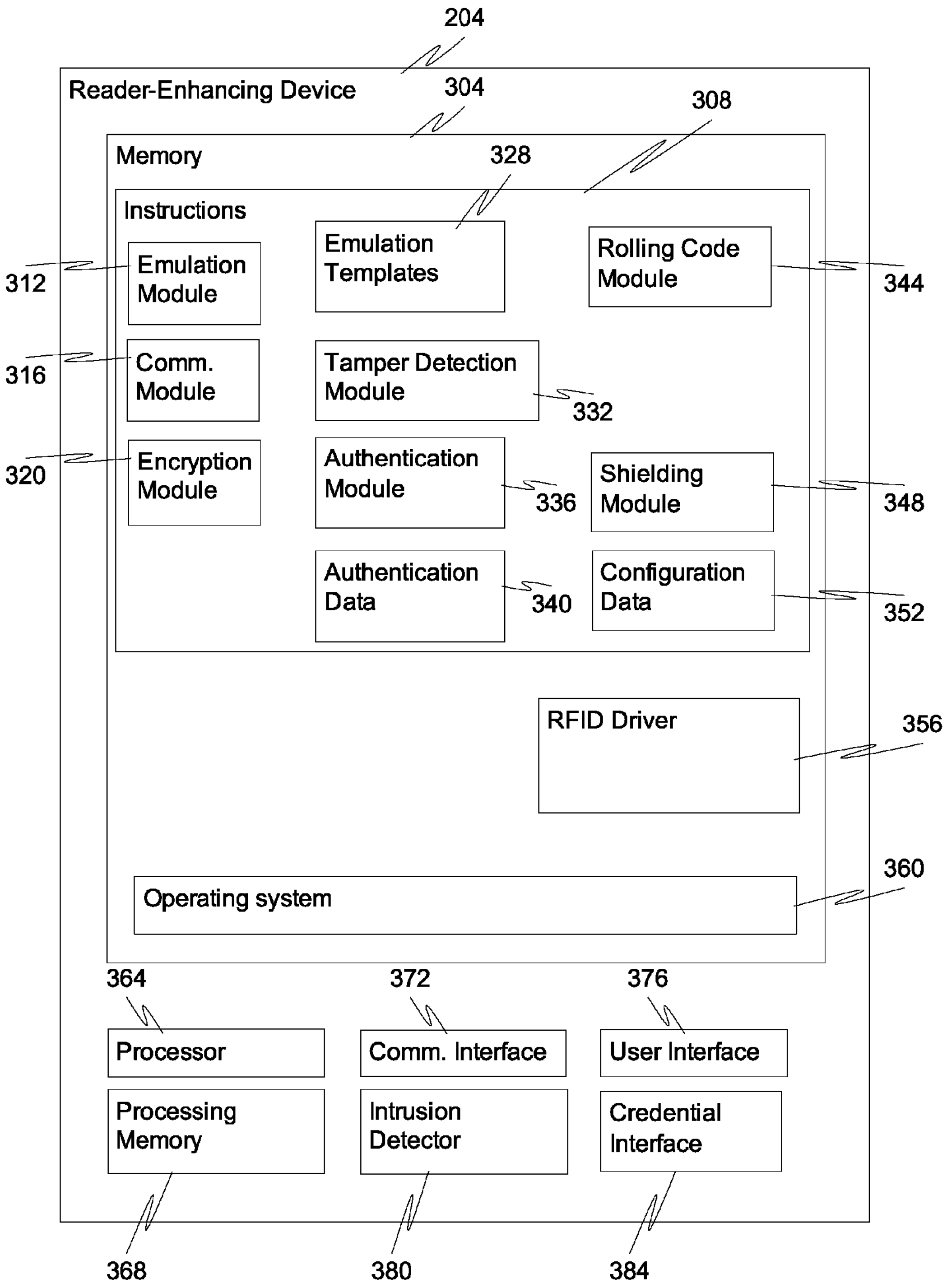

204
Reader-Enhancing Device
304
308
Memory
328
Instructions
312
Emulation Module
Emulation Templates
Rolling Code Module
344
316
Comm. Module
Tamper Detection Module
332
320
Encryption Module
Authentication Module
336
Shielding Module
348
Authentication Data
340
Configuration Data
352
RFID Driver
356
360
Operating system
364
372
376
Processor
Comm. Interface
User Interface
Processing Memory
Intrusion Detector
Credential Interface
368
380
384

Fig. 3

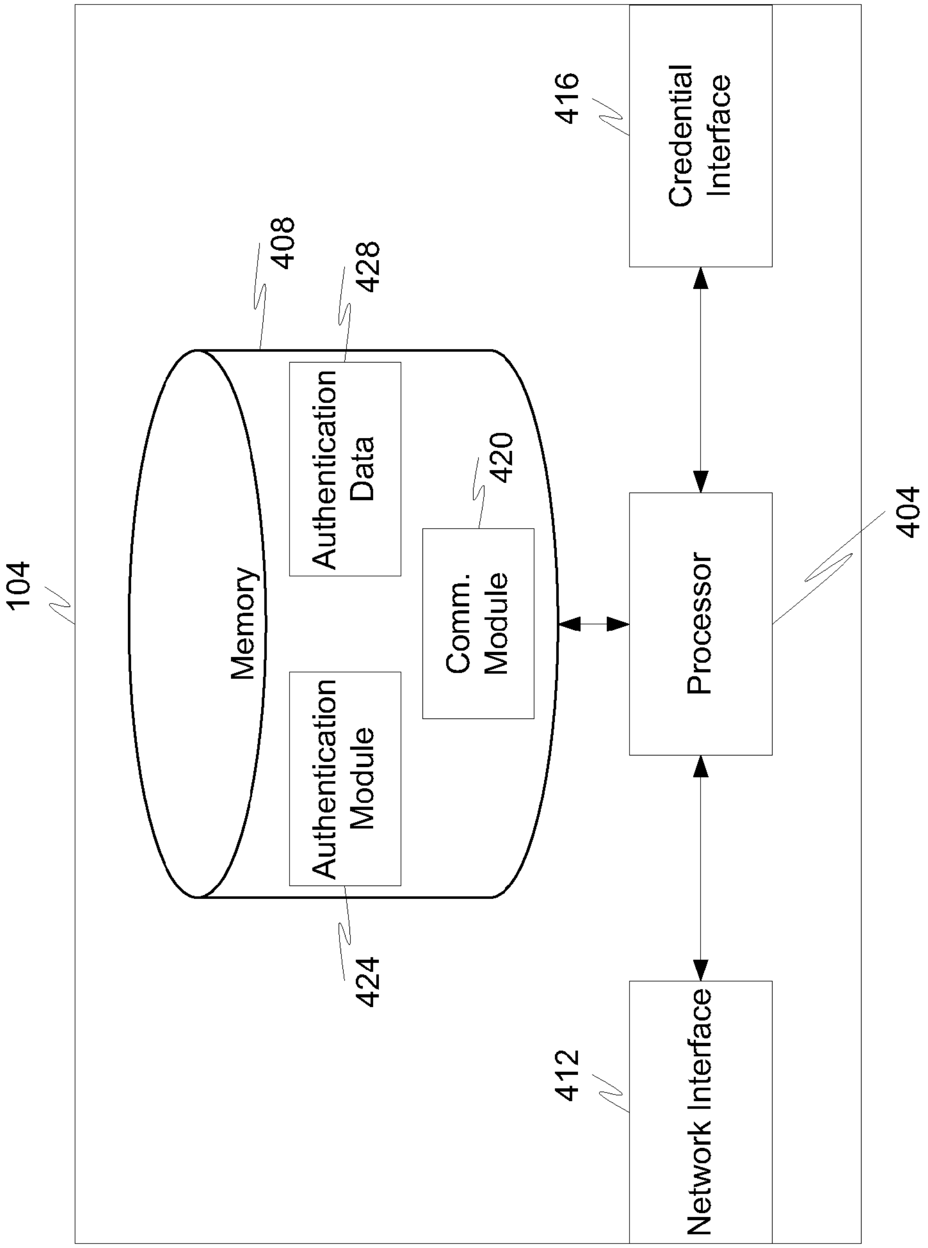

104
Memory
408
Authentication Data
428
Authentication Module
424
Comm. Module
420
Processor
404
Credential Interface
416
Network Interface
412

Fig. 4

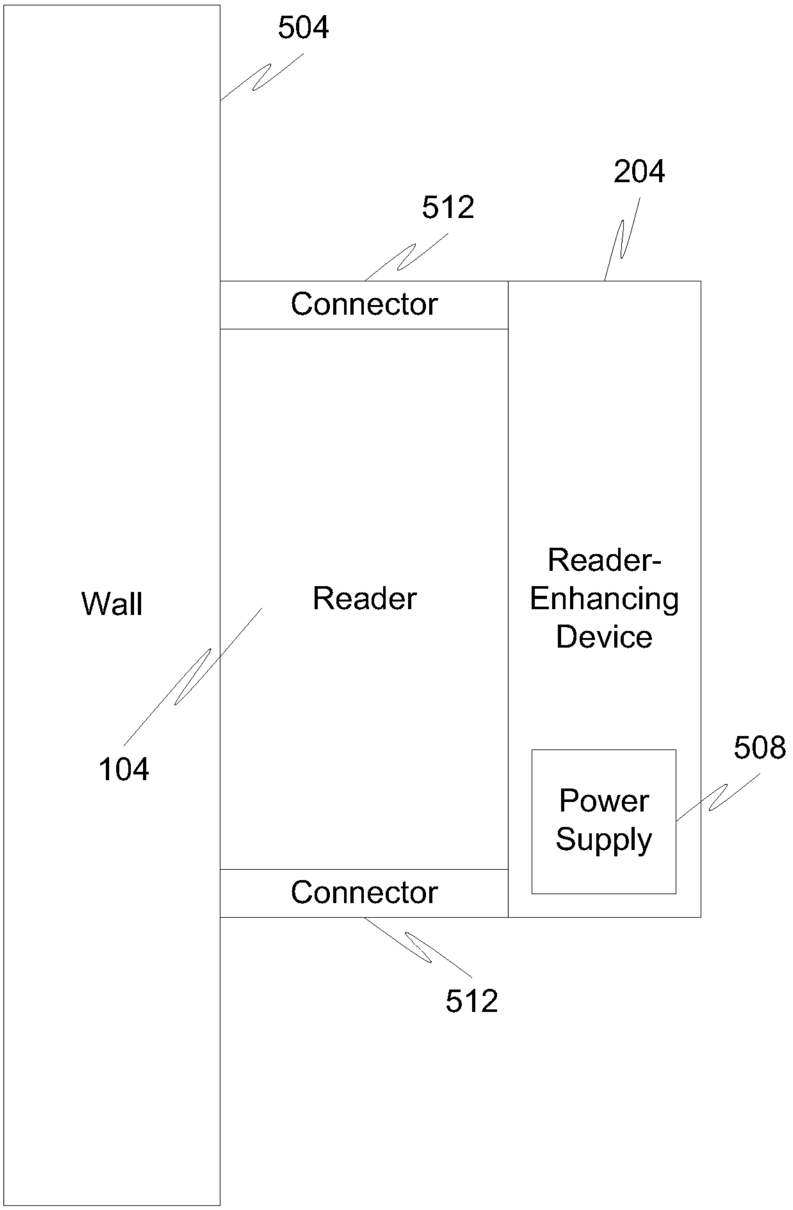

504
204
512
Connector
Wall
Reader
Reader-Enhancing Device
104
508
Power Supply
Connector
512

Fig. 5

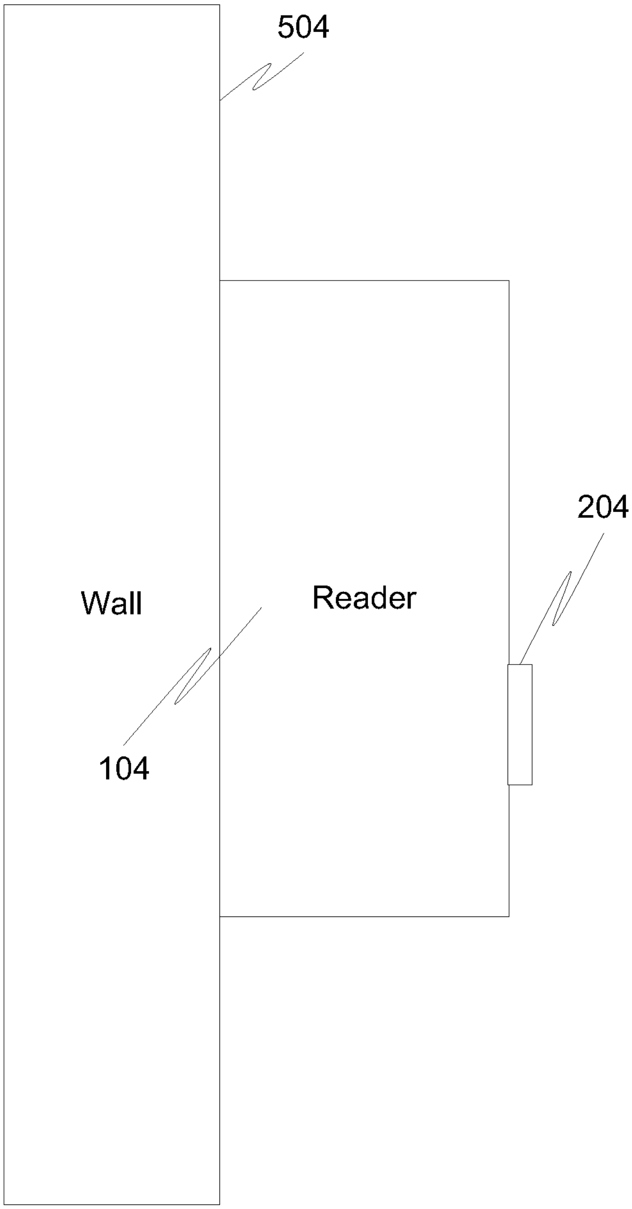


Fig. 6

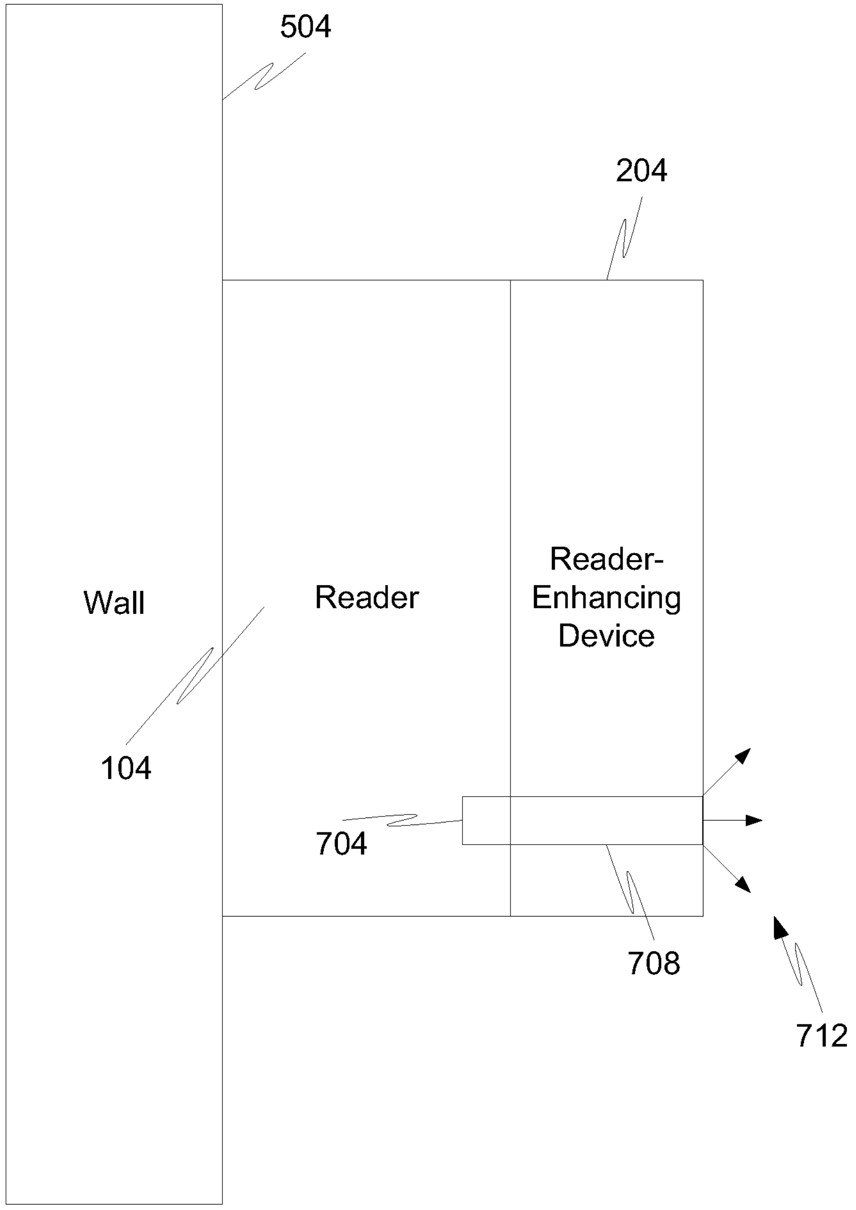


Fig. 7

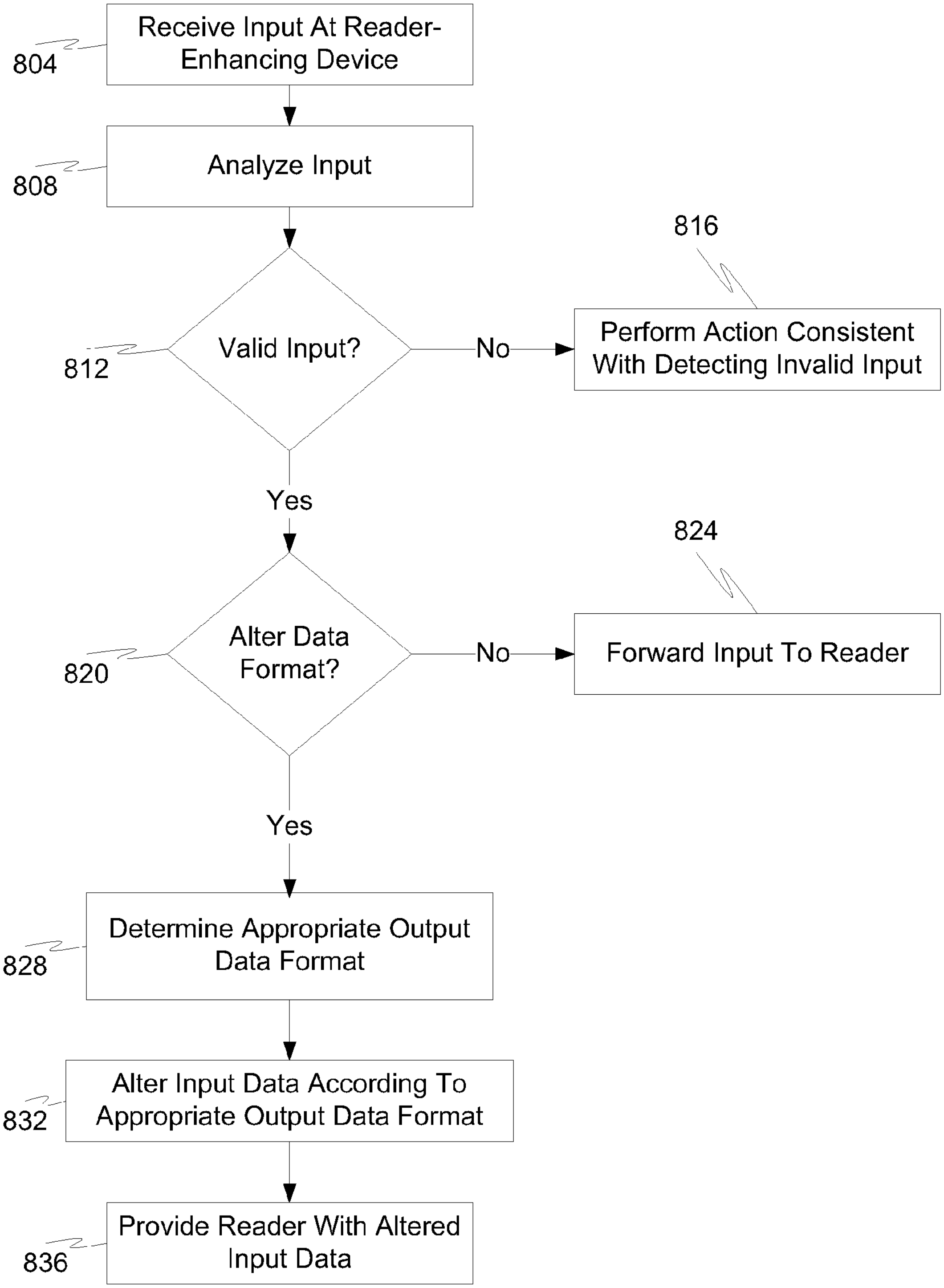

804
Receive Input At Reader-Enhancing Device
808
Analyze Input
812
Valid Input?
No
816
Perform Action Consistent With Detecting Invalid Input
Yes
820
Alter Data Format?
No
824
Forward Input To Reader
Yes
828
Determine Appropriate Output Data Format
832
Alter Input Data According To Appropriate Output Data Format
836
Provide Reader With Altered Input Data

Fig. 8

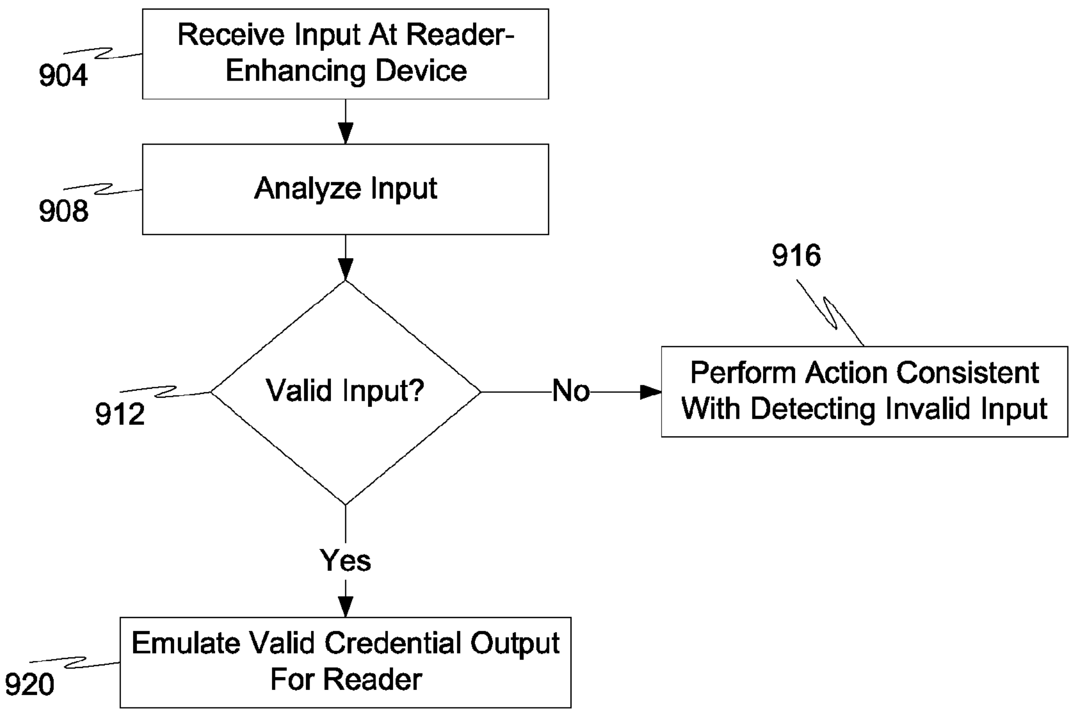

Receive Input At Reader-Enhancing Device
904
Analyze Input
908
916
Valid Input?
912
No
Perform Action Consistent With Detecting Invalid Input
Yes
Emulate Valid Credential Output For Reader
920

Fig. 9

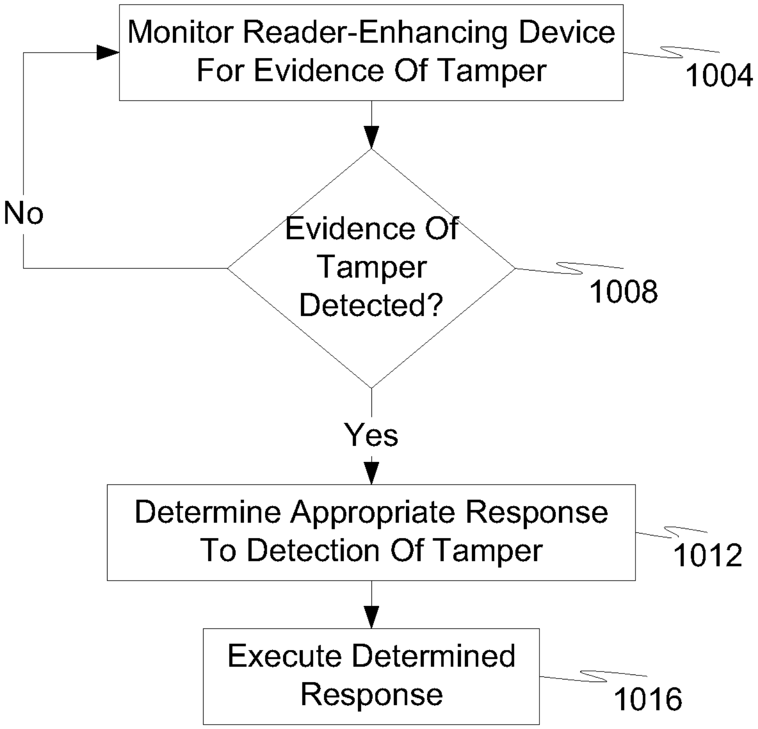

Monitor Reader-Enhancing Device For Evidence Of Tamper
1004
No
Evidence Of Tamper Detected?
1008
Yes
Determine Appropriate Response To Detection Of Tamper
1012
Execute Determined Response
1016

Fig. 10

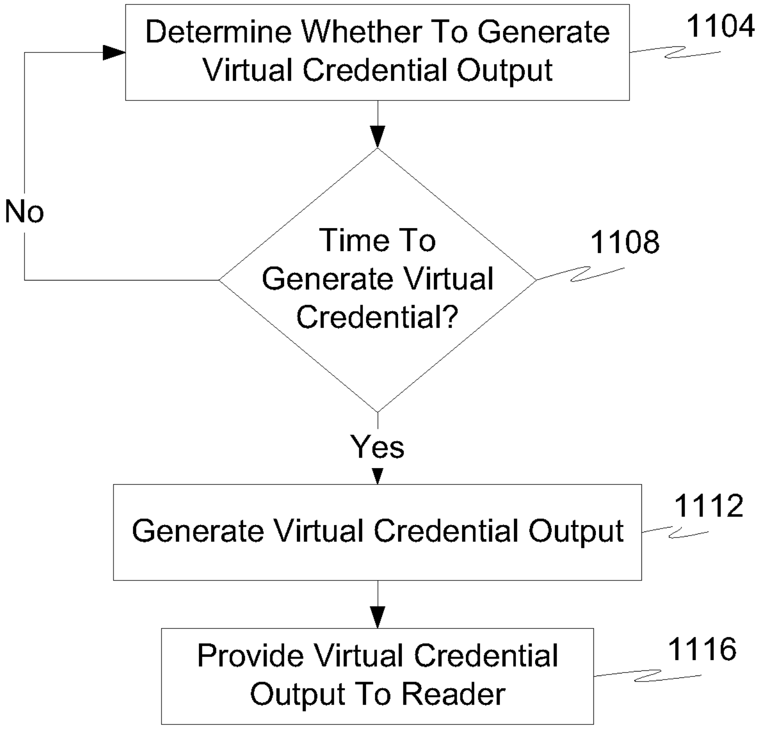

Determine Whether To Generate Virtual Credential Output
1104
No
Time To Generate Virtual Credential?
1108
Yes
Generate Virtual Credential Output
1112
Provide Virtual Credential Output To Reader
1116

Fig. 11

METHOD FOR UPGRADING RFID READERS IN SITU

CROSS REFERENCE TO RELATED APPLICATION

This application is a national stage application under 35 U.S.C. 371 of PCT Application No. PCT/US2012/029371 having an international filing date of Mar. 16, 2012, which designated the United States, which PCT application claimed the benefit of U.S. Application Ser. No. 61/453,844, filed Mar. 17, 2011, both of which are incorporated by reference in their entirety.

FIELD OF THE DISCLOSURE

The present disclosure is generally directed toward updating RFID readers.

BACKGROUND

Radio Frequency Identification (RFID) is a well established machine-readable technology used in many applications including physical access control and logical access control.

A specific initial type of RFID technology, 125 kHz proximity technology, displaced other popular predecessor technologies such as Wiegand and magnetic stripe due to its non-contact convenience and ability to work in harsh environmental locations as well as its higher immunity to vandalism. There now exits a need to move to a "next generation" RFID technology, which is currently ISO standardized and based on 13.56 MHz carrier frequencies. This second generation technology offers all of the advantages of its predecessor and adds higher security, more data memory, and multi-application capabilities.

Although this second generation RFID technology is now displacing the predecessor legacy 125 kHz proximity technology, there is still an extremely large installed base of both readers and credentials which utilize the 125 kHz proximity technology. It is estimated that tens of millions of legacy readers and hundreds of millions of legacy credentials are still in use, even though a superior second generation RFID technology is available. There are many approaches to tackling this enormous upgrade task and one solution includes replacing existing credentials with a multi-technology credentials that are compatible with both the legacy RFID technology and the second generation RFID technology in a single credential. Since this multi-technology credential can be read by both legacy 125 kHz RFID readers and newer 13.56 MHz RFID readers, once all of the credentials are replaced with multi-technology credentials, reader replacements can begin since the newly replaced credentials will work on both the legacy readers and the new readers. Unfortunately, this solution is a logistical nightmare, if implemented within a relatively short window of time, primarily because re-badging employees is very time consuming and costly.

Another solution, similar to the multi-technology card replacement method, focuses on the same approach in which existing legacy readers are replaced with multi-technology readers that are capable of reading both the legacy 125 kHz RFID credentials and the newer 13.56 MHz RFID credentials. However, since reader installation represents a significant portion of the upgrade costs due to the expense of both

skilled and trusted labor, it would be highly desirable to be able to simply and conveniently upgrade readers without actually replacing them.

The ideal solution would be to convert existing readers in situ while allowing for the natural transition of legacy credentials to new credentials in the normal course of business as employees are hired and fired or request replacement credentials that are lost or otherwise misplaced. Such a solution could be executed on a time scale that suits the needs of a site instead of a process that hastens the transition which is both disruptive and costly. Moreover, the ideal solution would not require existing readers to be removed from the wall to be replaced with either a new single technology replacement reader (after the original cards were all replaced with the new cards) or be replaced with a more costly multi-technology reader that supports both the legacy credential and the new credential.

SUMMARY

It is, therefore, one aspect of the present disclosure to provide a solution to the above-described problem by the use of a reader-enhancing device (e.g., face-plate, auxiliary device, attachment, etc.) that is attached to the front of, side of, or next to an existing RFID reader. As used herein, the term "existing RFID reader" will be used to mean the existing or installed reader. The reader-enhancing device would add the capability of reading the second generation credentials while still allowing the first-generation legacy credentials to be read. Although the term "face-plate" may generally be used to refer to the reader-enhancing device disclosed herein, one skilled in the art will appreciate that the "face-plate" does not necessarily have to be physically positioned on the face of an existing reader, nor does the device have to be provided in the form of a plate. Rather, any physical configuration of a device or collection of devices used to augment and/or enhance the operation of an existing reader by connecting on or near the reader are within this broad definition.

This reader-enhancing device has other desirable features as well. For example, it is well known that one of the current weak links in reader security is the communications between the reader and an upstream device. Modern communication protocols, such as TCP/IP, are much more secure than older protocols, but legacy readers typically use the Wiegand protocol which has been compromised by Zac Franken.

Embodiments of the present disclosure have overcome this security vulnerability by encrypting the data that is sent to the legacy reader by the emulation of a credential. Of course just encryption alone does not overcome replay attacks, so the encryption scheme utilized can employ a mechanism, such as a rolling code, to make sure that the credential data is different every time. Several schemes of implementing rolling codes to ensure this enhanced security is provided are described in U.S. Patent Publication Nos. 2006/0464912 and 2010/0034375 filed Aug. 16, 2006, and Aug. 10, 2009, respectively, both of which are incorporated herein by reference in their entirety. Of course, the encrypted changing credential data read by the legacy reader and subsequently sent to the upstream device must be received by an upstream device that contains the necessary algorithms to properly decode the received data.

Another security improvement of the present disclosure is that addition of a reader-enhancing device to a reader can be used to add a second factor of authentication to existing readers (be they legacy or second generation). Addition of a second factor of authentication renders cloned or spoofed credentials useless without the second authentication factor. One of the second factors of authentication that can be easily added to an existing legacy reader is a keypad (i.e., the first factor of authentication may correspond to the "something you have" in the form of the credential while the second factor of authentication may correspond to the "something you know" in the form of a user-provided PIN or password).

In some embodiments, the reader-enhancing device proposed herein is attached to the front of the original reader and utilizes as its power input at least some power provided from the RF field of the reader. When button presses are received at the reader-enhancing device, the reader-enhancing device then communicates either single button presses or a complete sequence of key presses by presenting encoded versions of the button presses to the reader as an emulated virtual credential. And with the greater memory and security functionality of the new credential technology, a PIN code could be securely stored in the credential itself and compared to the PIN entered and only emulated upon a successful comparison.

In a similar fashion to the keypad described above, biometric data could be used as the second factor of authentication (i.e., "something you are"). In such an embodiment, the reader-enhancing device added to the existing reader may comprise a biometric device. Similar to the keypad, the biometric device could be attached to the front of an already-installed reader. The biometric device may compare the received biometric data with a locally-maintained list of authorized user's biometric templates to determine if the biometric data matches at least one template stored thereon. If a match is found, the biometric device may then emulate a valid credential and provide such valid credential data to the existing reader on which the reader-enhancing device resides.

Also, to increase security of legacy technology, commonly used and readily available legacy formats could be turned off with the communications between the legacy (or existing) reader and the reader-enhancing device using either an obscure format or a more secure format, such as those described in U.S. Pat. No. 7,407,110 to Davis et al., the entire contents of which are hereby incorporated herein by reference.

Since many legacy readers can be programmed by the use of "configuration cards" also called "command cards" (examples of which are described in U.S. Pat. No. 7,392,943, the entire contents of which are hereby incorporated herein by reference, the reader-enhancing device described herein can automatically generate the required command cards to disable all formats except the one being used for communications between the reader and the reader-enhancing device. And, of course, the reader-enhancing device itself could use command cards to change its operating characteristics or even use cards or an NFC-enabled device to upgrade its firmware.

Another security enhancement which may be implemented with the reader-enhancing device described herein is that the reader-enhancing device may be configured to disable all legacy credentials from being read by the legacy reader by using a "jamming" technique in which the reader-enhancing device generates interference signals whenever legacy credentials are being read. Of course, the jamming is not done during the time the face-plate communicates with the legacy reader. Note that attempts to read a legacy credential during the time when face-plate to legacy communications are taking place would likely not work since there would be an RF collision that the legacy technology does not properly handle.

The present invention will be further understood from the drawings and the following detailed description. Although this description sets forth specific details, it is understood that certain embodiments of the invention may be practiced without these specific details. It is also understood that in some instances, well-known circuits, components and techniques have not been shown in detail in order to avoid obscuring the understanding of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is described in conjunction with the appended figures:

FIG. **1** is a block diagram of an access control system in accordance with embodiments of the prior art;

FIG. **2** is a block diagram of an access control system in accordance with embodiments of the present disclosure;

FIG. **3** is a block diagram depicting details of a reader-enhancing device in accordance with embodiments of the present disclosure;

FIG. **4** is a block diagram depicting details of a reader in accordance with embodiments of the present disclosure;

FIG. **5** is a block diagram depicting a first configuration of a reader-enhancing device in accordance with embodiments of the present disclosure;

FIG. **6** is a block diagram depicting a second configuration of a reader-enhancing device in accordance with embodiments of the present disclosure;

FIG. **7** is a block diagram depicting a third configuration of a reader-enhancing device in accordance with embodiments of the present disclosure;

FIG. **8** is a flow diagram depicting a first access control method in accordance with embodiments of the present disclosure;

FIG. **9** is a flow diagram depicting a second access control method in accordance with embodiments of the present disclosure;

FIG. **10** is a flow diagram depicting a tamper detection method in accordance with embodiments of the present disclosure; and

FIG. **11** is a flow diagram depicting a virtual credential generation method in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

The ensuing description provides embodiments only, and is not intended to limit the scope, applicability, or configuration of the claims. Rather, the ensuing description will provide those skilled in the art with an enabling description for implementing the described embodiments. It being understood that various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the appended claims.

FIG. **1** shows an illustrative embodiment of an access control system **100** in accordance with embodiments of the prior art. The reader **104** is generally provided at a strategic location to secure one or more assets. In some embodiments, the reader **104** is in communication with a control panel **108** via a first communication link. Such a reader **104** is referred to as a networked reader because the reader **104** provides some or all data used in making an access control decision to the control panel **108**. The control panel **108** comprises the necessary functionality to analyze the data received from the reader **104** and make an access control decision for the reader **104**. After the access control decision has been made at the control panel **108**, the control panel **108** which is enabled to either release one or more assets if a decision has been made to grant access or maintain such assets in a secure state if a decision has been made to deny access, communicates the results of the decision back to the reader **104** to let the user know results of the decision.

One function of a reader **104** is to control access to certain assets. More specifically, a reader **104** may be positioned at an access point for a given asset (e.g., a door for a room, building, or safe, a computer for electronic files, and so on). Unless a proper credential **112** is presented to the reader **104**, the access point is maintained in a secure state such that admittance or access to the asset is denied. If a credential **112** having authority to access the asset is presented to the reader **104**, then the reader **104** has the discretion to allow the user of the credential **112** access to the asset and implement various actions accordingly.

The credential **112** is a device that carries evidence of authority, status, rights, and/or entitlement to privileges for a holder of the credential **112**. A credential **112** is a portable device having memory and a reader interface (i.e., an antenna and Integrated Circuit (IC) chip) which enables the credential **112** to exchange data with the reader **104**. One example of a credential **112** is an RFID smartcard that has data stored thereon allowing a holder of the credential **112** to access an asset protected by a reader **104**. Other examples of a credential **112** include, but are not limited to, proximity cards, access control cards, credit cards, debit cards, passports, identification cards, key fobs, Near Field Communications (NFC)-enabled cellular phones, Personal Digital Assistants (PDAs), tags, or any other device configurable to include a transponder or some other machine-readable device.

As used herein, the terms a "holder" and a "user" are used interchangeably in reference to an individual or an object associated with credential **112**.

As noted above, the control panel **108** may be responsible for making some or all of the asset-access decisions based on data received at the reader **104** from the credential **112**. In some embodiments, the reader **104** may not be connected to a control panel **108**, in which case the reader **104** is referred to as a stand-alone reader. Stand-alone readers comprise the decision-making components necessary to analyze data received from a credential **112** and determine if the holder thereof is entitled to access an asset secured by the reader **104**. Stand-alone readers are generally desirable in situations where a reader **104** is in an isolated location and a communication link between the control panel **108** and reader **104** is not easily established.

In configurations where the reader **104** is a networked reader, a communications network may be used to establish the communication link between the reader **104** and control panel **108**. Exemplary communication networks may provide bi-directional communication capabilities, which may selectively be implemented in a form of wired, wireless, fiber-optic communication links, or combinations thereof. Even though the communication link between the control panel **108** and reader **104** is depicted as bi-directional, one skilled in the art can appreciate that the communication link may be unidirectional. As one example, the reader **104** may utilize the Wiegand protocol to communicate with the control panel **108**.

The communication link between the reader **104** and control panel **108** may be implemented utilizing buses or other types of device connections. The protocols used to communicate between the control panel **108** and the reader **104** may include one or more of the TCP/IP protocol, RS 232, RS 485, Current Loop, Power of Ethernet (POE), Bluetooth, Zigbee, GSM, WiFi, and other communication methods and protocols known in the art.

The control panel **108** may be a general-purpose computer adapted for multi-task data processing and suitable for use in a commercial setting. Alternatively, the control panel **108** may be implemented as a host computer or server and the reader **104** can be connected to the host computer via a TCP/IP connection or other type of network connection. A memory comprising a database of records for the system **100** may be associated with the control panel **108**. The database, although not depicted, may be integral with or separated from the control panel **108** or it may be incorporated into the reader **104**. The database maintains records associated with the readers **104**, credentials **112** and their respective holders or users, algorithm(s) for acquiring, decoding, verifying, and modifying data contained in the readers **104**, algorithm(s) for testing authenticity and validity of the credentials **112**, algorithm(s) for implementing actions based on the results of these tests, and other needed software programs. Specific configurations of the control panel **108** are determined based on and compliant with computing and interfacing capabilities of the readers **104**.

As can be appreciated by one of ordinary skill in the art, the system **100** is limited to the capabilities of the reader **104**. Thus, if the reader **104** is only configured to read a certain type of credential **112** or receive a certain type of input from a user, then the reader **104** will not be compatible for use with other credentials **112**, which may provide increased security mechanisms than the credentials **112** with which the reader **104** is natively compatible. Likewise, if the reader **104** is only natively configured to verify a first factor of authentication (e.g., something a user has as evidenced by the credential **112**), then the reader **104** will not be as secure as other readers which offer multi-factor authentication features (e.g., the ability to verify some a user has, something a user knows, something a user is, etc.). Accordingly, increasing the security of the system **100** is generally dependent upon updating the reader **104** functionality, which has traditionally been a costly endeavor.

FIG. **2** depicts an exemplary access control system **200** in which the capabilities of the reader **104** are enhanced without physically replacing the reader **104** with an updated or upgraded reader. In particular, the access control system **200** includes a reader-enhancing device **204** that is in communication with the reader **104**. The reader-enhancing device **204** enables the reader **104** to be compatible with both a first type of credential **112** (i.e., a legacy credential of the type which the reader **104** is natively compatible) and a second type of credential **208** (i.e., another credential that is different from the first type of credential **112**). In some embodiments, the second credential **208** comprises additional security features and/or utilizes a different communication protocol to exchange data with the reader **104**. In some embodiments, the first credential **112** is tuned to exchange messages with the reader **104** by using a carrier frequency of approximately 125 kHz whereas the second credential **208** is tuned to exchange messages with the reader **104** by using a carrier frequency of approximately 13.56 MHz.

The reader-enhancing device **204**, in some embodiments, acts as a communications conduit between the reader **104** and both types of credentials **112**, **208**. In some embodiments, the reader **104** may still be enabled to communicate directly with the first type of credential **112**, whereas the reader-enhancing device **204** is configured to read data from the second type of credential **208** on the reader's **204** behalf and (1) alter such data before providing the data to the reader

104 and/or (2) analyze such data and emulate a first type of credential if the data read from the second type of credential **208** is validated.

Another possible interaction between the reader **104** and reader-enhancing device **204** may include the reader-enhancing device **204** selectively or completely jamming communications between all credentials and the reader **104** such that all types of credentials are forced to communicate with the reader **104** through the reader-enhancing device. In some embodiments a passive jamming mechanism (e.g., metal plate, wire mesh, or any other interference-inducing material) may be utilized to interfere with communications of the reader **104**. In some embodiments, an active jamming mechanism (e.g., selectively-engageable antenna which creates noise in the environment about the reader **104**) may be utilized to interfere with communications of the reader **104**. In may be the case that active jamming mechanisms are utilized to preclude wireless communications in a certain bandwidth or carrier frequency, whereas other jamming mechanisms are utilized to preclude all wireless communications.

Still another function of the reader-enhancing device **204** may be to add an additional factor of authentication to the access control system **100**. In some embodiments, the reader **104** may only be natively configured to analyze a single factor of authentication. Thus, if that single factor of authentication is compromised (e.g., a first type of credential **112** is lost or stolen or a password or PIN has been compromised), then the security of the entire system **100** is at risk. Requiring a second factor of authentication (or more) ensures that no single breach in security will result in a complete compromise of the access control system **200**. As one example, the reader-enhancing device **204** may comprise functionality which enables the reader-enhancing device **204** to receive, as an input, data related to both a first and second factor of authentication.

In some embodiments, the reader-enhancing device **204** may allow communications related to the first factor of authentication to pass directly to the reader **104** where they are either analyzed or subsequently provided to the control panel **108** for analysis. The reader-enhancing device **204** may also require, as a prerequisite to passing communications related to the first factor of authentication to the reader **104**, that a user provide a second factor of authentication. Only upon determining that the second factor of authentication is valid does the reader-enhancing device allow the communications related to the first factor of authentication to pass to the reader **104**. Therefore, the reader-enhancing device **204** provides an additional layer of security to the access control system **200** without requiring the replacement of the reader **104**. To the contrary, the reader-enhancing device **204** enables the reader **104** to operate in its normal fashion while simultaneously providing additional security features to the system **200**.

Although wireless communication links are depicted in FIGS. **1** and **2** as being established between a credential **112**, **208** and a reader **104** or reader-enhancing device **204**, one skilled in the art will appreciate that one or both types of credentials **112**, **208** may be contact-based credentials and the communications between the credentials **112**, **208** and the reader **104** or reader-enhancing device **204** may be contingent upon establishing contact between the devices. In some embodiments, one or both types of credentials **112** may comprise a magstripe card, a Wiegand card, or the like.

Additionally, it is not necessary that the reader-enhancing device **204** enable the reader **104** to communicate with multiple types of credentials **112**, **208**. Rather, the reader-enhancing device **204** may be configured to receive different types of inputs (e.g., keypad inputs, voice inputs, image inputs, etc.). The reader-enhancing device **208** may then either alter the different types of inputs to emulate an input of a first type of credential **112** or the reader-enhancing device **208** may analyze the different types of inputs, determine their validity, and emulate a valid credential if the analysis of such inputs determines that the inputs are valid. In some embodiments, the reader-enhancing device **208** may always emulate the same valid credential using the same data contained on the original legacy credential or the reader-enhancing device **208** may have a list of valid credential values that are sequentially or randomly provided to the reader **104** upon determining that a valid input has been received at the reader-enhancing device **204**. It may even convert one manufacturer's credential into another manufacturer's credential similar to the paradigm discussed in U.S. Patent Publication No. 2014/0320261 A1 to Davis et al., the entire contents of which are hereby incorporated herein by reference. And it may even add additional security features to the original credential data so that it passes through the original reader through the communications path in a more secure fashion than it would have if merely the original credential data was converted into the new credential.

With reference now to FIG. **3**, additional details of a reader-enhancing device **204** will be described in accordance with embodiments of the present invention. The reader-enhancing device **204** may comprise memory **304** that includes a number of instructions **308**, modules, and other data structures as well as a processor **364** for executing the instructions **308** and other contents of memory **304**.

The reader-enhancing device **204** may also include a communication interface **372** which allows the reader-enhancing device **204** to communicate with a reader **104**. Exemplary types of communication interfaces **372** include, without limitation, an RF antenna and driver, an infrared port, a fiber optics interface, a Universal Serial Bus (USB) port, or the like.

The reader-enhancing device **204** may further include a credential interface **384** which enables the reader-enhancing device **204** to communication with one, two, three, or more different types of credentials **112**, **208**. The credential interface **384** facilitates communications between the reader-enhancing device **204** credentials **112**, **208**. The type of credential interface **384** provided on the reader-enhancing device **204** may vary according to the type of credential **112**, **208** that is in the system **100**, **200**. In some embodiments, the credential interface **384** includes one or more of an antenna, an array of antennas, an infrared port, an optical port, a magnetic stripe reader, a barcode reader or similar machine-vision components, a Near Field Communications (NFC) interface, or any other component or collection of components which enables the reader-enhancing device **204** to communicate with credentials **112**, **208** and other portable memory devices. In some embodiments, the credential interface **384** enables the reader-enhancing device **204** to read one or more non-RFID machine-readable credentials including one or more of magnetic stripe cards, bar codes, Wiegand cards, Hollerith, infrared, Dallas 1-wire, and barium ferrite.

In some embodiments, the credential interface **384** and communication interface **372** are of the same type (i.e., RF communication interfaces). In some embodiments, the credential interface **384** and communication interface **372** are implemented as a single interface. Thus, the reader-enhancing device **204** may be enabled to communicate with credentials **112**, **208** and readers **104** by using the same hardware components.

In addition to a communication interface **372**, the reader-enhancing device **204** may include a user interface **376** which facilitates user interaction with the reader-enhancing device **204** as well as the reader **104** via the reader-enhancing device **204**. The user interface **376** may include one or more user inputs, one or more user outputs, or a combination user input/output. Exemplary user inputs include, without limitation, keypads, buttons, switches, microphones, fingerprint scanners, retinal scanners, cameras, and the like. Exemplary user outputs include, without limitation, lights, display screens (projection, LCD, LED array, plasma, etc.), individual LED, speakers, buzzers, etc. Exemplary combination user input/outputs may include a touch-screen interface or any other type of interface which is capable of simultaneously displaying a user output and receiving a user input.

In addition to memory **304**, the reader-enhancing device **204** may also include processing memory **368**, which may be in the form of a Randomly Accessible Memory (RAM), cache memory, or any other type of memory used to facilitate efficient processing of instructions **208** by the processor **364**.

Whereas the processing memory **368** is used to temporarily store data during processing tasks, the memory **304** is provided to store permanent instructions **308** which control the operational behavior of the reader-enhancing device **204**. The memory **304** and/or **368** may be implemented using various types of electronic memory generally including at least one array of non-volatile memory cells (e.g., Erasable Programmable Read Only Memory (EPROM) cells or FLASH memory cells, etc.) The memory **304** and/or **368** may also include at least one array of dynamic random access memory (DRAM) cells. The content of the DRAM cells may be pre-programmed and write-protected thereafter, whereas other portions of the memory may selectively be modified or erased.

The various routines and modules which may be included in memory **304** comprise one or more of an emulation module **312**, a communication module **316**, an encryption module **320**, emulation templates **328**, a tamper detection module **332**, an authentication module **336**, authentication data **340**, a rolling code module **344**, a shielding module **348**, and configuration data **352**.

The tamper detection module **332** may comprise software and/or hardware that enables the reader-enhancing device **204** to detect potential attacks on the reader-enhancing device **204** and attempts to circumvent security features of the reader-enhancing device **204**. In some embodiments, the tamper detection module **332** is enabled to determine that an invalid credential **112**, **208** has been presented to the reader-enhancing device **204** or some other false user input has been provided to the reader-enhancing device **204**. In response to detecting such an event, the reader-enhancing device **204** may increment a counter. If a predetermined number of these types of events are detected within a predetermined amount of time, then the reader-enhancing device **204** may implement one or more security measures to protect the reader-enhancing device **204** and data stored thereon. In particular, the reader-enhancing device **204** may temporarily slow down processing speeds, temporarily discontinue operations, sound an alarm, notify one or more security personnel, and the like.

As can be seen in FIG. **3**, an intrusion detector **380** may also be provided in a physical form rather than or in addition to being provided as tamper-detection instructions **332** in memory **304**. For example, a physical intrusion detector **380** may be provided that locks one or more user inputs, secures memory **304** such that it cannot be physically accessed without destroying some or all of the data stored thereon, detects a physical disconnection of the reader-enhancing device **204** and reader **104**, detects an attempt to tamper with the physical connection of the reader-enhancing device **204** and reader **104**, and the like.

In some embodiments, the intrusion detector **380** and/or tamper detection module **332** are configured to determine that an attack or potential attack on the reader-enhancing device **204** or reader **104** is under way and in response to making such a determination perform one or more counter-tamper actions: erasing keys and other sensitive data stored in memory **304**, removing encryption keys from the reader-enhancing device **204**, disabling the reader-enhancing device **204** and/or reader **104** from operating, and setting a flag in a non-volatile securely stored memory location.

The communication module **316** provides instructions which enable the reader-enhancing device **204** to communicate with other devices. In particular, the communication module **316** may comprise message encoding and/or decoding instructions, message encryption and/or decryption instructions, compression and/or decompression instructions, trans-coding instructions, and any other known type of instructions which facilitate communications over a communications network. For example, the communication module **316** may comprise instructions which enable the reader-enhancing device **204** to create one or more messages or communication packets which are appropriately formatted and transmitted in accordance with a known communication protocol via the communication interface **372**. Likewise, the communication module **316** may also comprise instructions which enable the reader-enhancing device **204** to format messages received over the communication interface **372** for processing by various other components of the reader-enhancing device **204**.

In addition to enabling the reader-enhancing device to communicate via communication interface **372**, the communication module **316** may also be configured to enable the reader-enhancing device **204** to communicate with different types of credentials **112**, **208** via the credential interface **384**. Accordingly, the communication module **316** may be responsible for formatting commands that are transmitted to a credential **112**, **208** as well as receiving messages from credentials **112**, **208** and formatting them such that they can be processed by other routines in the instructions **308** or such that they can be forwarded on to the reader **104** in a format understood by the reader **104**.

The communication module **316**, in some embodiments, may be configured to work in conjunction with an encryption module **320**. The encryption module **320** may comprise one or more encryption keys (public and/or private) as well as one or more encryption algorithms that can be used to secure communications between the reader-enhancing device **204** and other devices, such as a reader **104** and/or credential **112**, **208**. The encryption module **320** may be configured to always encrypt messages before they are transmitted by the reader-enhancing device **204** or the encryption module **320** may be configured to selectively encrypt certain messages having certain qualities. For example, the encryption module **320** may be configured to only encrypt emulated credential messages before they are sent to the reader **104** whereas other messages are sent without encryption.

The instructions **308** may further comprise an emulation module **312** that is configured to act as a credential emulator, which enables the reader **104** to communicate with types of credentials that it is not natively designed to communicate with. In particular, the emulation module **312** may be configured to emulate messages in a format consistent with the first type of credential **112** (i.e., the type of credential with which the reader **104** is natively capable of communicating with). The emulation module **312** may also be configured to generate credential data representing a first type of credential **112** that is recognized as valid by the reader **104** (or control panel **108**). The emulation module **312** may generate such credential data by referencing the emulation templates **328** which comprise a list of possible valid credentials of the first type. When the emulation module **312** is invoked, the emulation module **312** may select one or more entries in the emulation templates **328** and generate a message that is transmitted from the reader-enhancing device **204** to the reader **104** in a format consistent with the first type of credential **112**.

In some embodiments, the emulation templates **328** may be provided as a list (ordered or random) of credential data recognized as valid by the reader **104**. As an additional security feature, the emulation module **312** may utilize a rolling code module **344** to assist in determining what credential data should be used from the emulation templates **328** in generating a message for transmission to the reader **104**. In particular, the reader-enhancing device **204** may determine that it needs to emulate a first type of credential **112** for the reader **104** and in response to making such a determination, the emulation module **112** may invoke the rolling code module **344** to select credential data from the emulation templates **328**. The selected credential data is then used by the emulation module **312** to generate one or more messages which simulate messages that are transmitted by the first type of credential **112**.

In some embodiments, the rolling code module **344** may select credential data from the emulation templates **328** according to a predetermined selection pattern or with a predetermined selection algorithm. In some embodiments, the rolling code module **344** may alter the selection algorithm used after the reader-enhancing device **204** has been operating for a predetermined amount of time or after the reader-enhancing device **204** has received a prompting signal from the reader **104** indicating that a new selection algorithm should be utilized. Other operational features of the rolling code module **344** are discussed in U.S. Patent Application Nos. 2006/0464912 and 2010/0034375, both of which are incorporated herein by reference in their entirety.

Another module which may be provided in the instructions **308** is an authentication module **336** that is capable of receiving authentication data from a credential **112**, **208**, analyzing the authentication data, and determining if the received authentication data corresponds to valid authentication data. In some embodiments, the authentication module **336** may refer to authentication data **340** which is also stored in memory **304**. In some embodiments, the authentication data **340** may comprise a list of valid or authorized credentials and their corresponding credential data. Alternatively, the authentication data **340** may comprise algorithms for analyzing authentication data and determining if such data is valid. In some embodiments, the initiation of the emulation module **312** may be contingent upon the authentication module **336** successfully determining that data received from a credential **112**, **208** is valid credential data.

A shielding module **348** may also be provided as instructions **308** in memory **304**. In particular, the shielding module **348** may be configured to block some or all communications between the reader **104** and credentials **112**, **208**. In some embodiments, the shielding module **348** actively determines if a first type of credential **112** is within proximity (i.e., read range) of the reader **104** and, if so, generates a scrambling signal or noise which precludes the reader **104** from reading the first type of credential **112**. In some embodiments, the scrambling signal corrupts credential data as it is transmitted from the first type of credential **112** to the reader **104**.

Configuration data **352** may also be maintained in memory **304**. In some embodiments, the configuration data **352** describes operating characteristics of the reader **104** such as the reader's **104** frequency variation, operating frequency, power levels, polling rate, and timing characteristics. Other characteristics of the reader **104** include, without limitation, reader model number, firmware version, reader identifier, and other data which describes the reader **104**. The characteristics of the reader **104** may be inherent characteristics or provisioned characteristics.

In some embodiments, the configuration data **352** may also comprise characteristics of the reader-enhancing device **204**. For example, the configuration data **352** may describe capabilities of the reader-enhancing device **204**, identification information of the reader-enhancing device **204**, and the like. The configuration data **352** may also define data that is common to all credentials **112**, **208** at a given location (e.g., by site code or company ID). If credentials are read by the reader-enhancing device **204** that do not present the common site code or company ID, then the reader-enhancing device **204** may reject messages received from such credentials or interfere with communications between such credentials and the reader **104**. This ensures that the reader **104** is prevented from communicating with credentials **112**, **208** that do not belong to a particular subset of credentials.

In some embodiments, a communications channel is established with the reader-enhancing device **204** via the communication interface **372** or credential interface **384**. A control panel **108** or some other administrative device may be configured to communicate with the reader-enhancing device **204** via the communications channel to change one or more operating characteristics of the reader-enhancing device **204**. The communications channel may utilize one or more of RF, light, and audio as a message-transmitting medium and messages may be exchanged via the communication channel using one or more of the following protocols Ultra-High Frequency (UHF), Bluetooth, WiFi, Zigbee, and infrared light.

In accordance with at least some embodiments of the present disclosure, the tamper detection module **332** may be configured to "memorize" the characteristics of the reader **104** with which the reader-enhancing device **204** is configured to operate with. In the event that the tamper detection module **332** detects that the reader-enhancing device **204** is trying to operate in connection with a reader **104** that does not possess the memorized characteristics, the tamper detection module **332** may determine that the reader-enhancing device **204** has been improperly removed from the reader **104** and may limit operating capabilities of the reader-enhancing device **204** or, in some embodiments, disable the reader-enhancing device **204**.

Other components of memory **204** may include a Personal Computer/Smart Card (PC/SC) (not depicted), an RFID driver **356**, and an operating system **360**, which is a high-level application that facilitates interactions between various other modules and applications in memory **204** and hardware components of the reader-enhancing device **204**. The PC/SC and RFID driver **356** may be responsible for facilitating credential **112**, **208** integration into the computing environment of the reader-enhancing device **204**. In some embodiments, the first type of credential **112** and reader-enhancing device **204** utilize a first set of communication protocols to communicate with one another. Similarly, the second type of credential **208** and reader-enhancing device **204** may utilize a second set of communication protocols, different from the first set of communication protocols, to communicate with one another. All other communications and processing components of the reader-enhancing device **204** are carried out in another protocol that is different than the first and second communication protocols. The PC/SC in combination with the RFID driver **356** may facilitate interactions between the reader-enhancing device **204** and credentials **112**, **208** and integrate messages received from a credential **112**, **208** or any other type of user input into the appropriate format such that they can be handled by the various modules stored as instructions **308**. The RFID driver **356** may also include commands for controlling operations of the credential interface **384** and/or communication interface **372**.

The processor **304** may include any general-purpose programmable processor, digital signal processor (DSP) or controller for executing application programming. Alternatively, the various modules described herein may be implemented as hardware or firmware rather than software and the processor **304** may comprise a specially configured Application Specific Integrated Circuit (ASIC).

With reference now to FIG. **4**, additional details of a reader **104** will be described in accordance with at least some embodiments of the present disclosure. The reader **104** may be a conventional type of reader or a low-power reader such as those described in U.S. Pat. No. 7,782,209 to Lowe et al., the entire contents of which are hereby incorporated herein by reference.

In some embodiments, the reader **104** may comprise a processor **404**, memory **408**, a network interface **412**, and a credential interface **416**. The processor **404** may be similar or identical to the processor **304** of the reader-enhancing device **204**, meaning that the processor **404** may have the same general processing capabilities as the processor **304**.

Similarly, the memory **408** may be similar or identical to the memory **304**, **368** provided on the reader-enhancing device **204**. For example, the memory **408** may be volatile or non-volatile. Examples of non-volatile memory include, but are not limited to, Read Only Memory (ROM), Erasable Programmable ROM (EPROM), Electronically Erasable PROM (EEPROM), Flash memory, and the like. Examples of volatile memory include Random Access Memory (RAM), Dynamic RAM (DRAM), Static RAM (SRAM), or buffer memory. In one embodiment, the memory **408** and the processor **404** are designed to utilize known security features to prevent unauthorized access to the contents of the memory **408** such as side channel analysis and the like.

The memory **408** may contain one or more modules which enable the functionality of the reader **104**. In particular, the reader **104** may comprise a communication module **420**, an authentication module **424**, and authentication data **428**. The communication module **420** enables the reader **104** to communicate with the first type of credentials **112** as well as communicate with the control panel **108**. In some embodiments, separate communication modules may be provided where one communication module supports reader-to-credential communications and another communication module supports reader-to-control panel communications.

In some embodiments, the communication module **420** is natively configured to enable the reader **104** to communicate only with a first type of credential **112** or receive a particular type of user input. Accordingly, the communication module **420** limits the functionality of the reader **104** as a stand-alone device.

Likewise, the authentication module **424** is configured to analyze credential data from the first type of credential **112**. In some embodiments, the authentication module **424** is configured to analyze credential data from the first type of credential **112** by comparing credential data received at the credential interface **416** with the authentication data **428**. In some embodiments, data in the authentication data **428** matches data in the emulation templates **328**. Accordingly, the emulation templates **328** may be used to generate credential data for the reader **104** that is already known to correspond to a valid input when analyzed by the authentication module **424**.

The network interface **412** enables the reader **104** to communicate with networked devices, such as control panel **108**. Exemplary types of network interfaces **412** include, without limitation, Ethernet ports, antennas, Universal Serial Bus (USB) ports, serial data ports, parallel data ports, Small Computer Systems Interface (SCSI) ports, interfaces supporting cellular communications via known cellular communication protocols, and the like.

The credential interface **416** is designed to enable the reader **104** to communicate with credentials **112**. As one example, the credential interface **416** may comprise one or more antennas and antenna drivers which enable the reader **104** to exchange messages wirelessly with the first type of credential **112**. In some embodiments, the reader-enhancing device **204** is configured to communicate with the reader **104** via the credential interface **416**. This feature is accomplished by virtue of the fact that the reader-enhancing device **204** comprises an emulation module **312** which is configured to emulate credentials of the first type **112** (i.e., generate and transmit messages to the reader **104** in the same format and according to the same protocols that the first type of credential **112** would use to communicate with the reader **104**). Accordingly, the credential interface **416** may enable the reader **104** to communicate with one or both of the first type of credential **112** and the reader-enhancing device **204**.

Although not depicted, the reader **104** may also include a user interface that is similar to the user interface **376**. Such a user interface may support user interaction with the reader **104**.

With reference now to FIG. **5**, a first exemplary physical configuration of the reader **104** and reader-enhancing device **204** will be described. The reader **104**, in one embodiment, may be mounted to a wall **504** via one or more mounting mechanisms (e.g., screws, nails, hangers, fasteners, adhesives, or the like). Although it is not necessary to mount the reader **104** to a wall **504**, but instead mount the reader **104** to some other stationary or mobile asset. Accordingly, although discussions of the physical configurations will generally refer to a reader **104** mounted on a wall **504**, embodiments of the present disclosure are not so limited.

In the first exemplary physical configuration, the reader-enhancing device **204** may be mounted to the reader **104** as a reader face-plate. In other words, the reader-enhancing device **204** may be dimensioned such that the silhouette of the reader-enhancing device **204** matches or substantially matches the silhouette of the reader **104**. In some embodiments, the reader-enhancing device **204** may be configured to replace an original face-plate of the reader **204**.

In embodiments where the reader-enhancing device **204** is configured as a face-plate or variant thereof, the reader enhancing device **204** may be connected to one or both of the reader **104** and wall **504** via connectors **512**. The connectors **512** may correspond to one or more physical components which connect the reader-enhancing device **204** to the reader **104** or wall **504**. In some embodiments, the connectors **512** connect to mounting holes provided on the reader **104**. The connectors **512** may be integral parts of the reader-enhancing device **204** that latch, hook, screw, or otherwise mate with a portion of the reader **104**. In other embodiments, the connectors **512** may be separate components that latch, hook, screw or otherwise mate with a portion of the reader-enhancing device **204** and reader **104**.

As can be seen in FIG. **5**, the reader-enhancing device **508** may be provided with its own power supply **508**. In some embodiments, the power supply **508** may correspond to a battery or set of batteries, a capacitor or set of capacitors, a super-capacitor or set of super-capacitors, a solar cell or array of solar cells, an antenna or set of antennas (for converting energy from an RF field generated by the reader **104** into the power supply for the reader-enhancing device **204**), and/or a power adaptor or converter for receiving and converting an external power supply from either an external power outlet or from the reader **104**.

In some embodiments, the power supply **508** corresponds to an antenna that is tuned to have an impedance that matches an impedance of the credential interface **416**. Therefore, when an RF field is generated by the credential interface **416**, the power supply **508** is capable of converting at least some energy from the RF field into energy that is used to power the components of the reader-enhancing device **204**. In some embodiments, however, it may be desirable to supplement the power supply **508** to enable the reader-enhancing device **204** to operate during periods in which the reader **104** is not generating an RF field. Accordingly, the power supply **508** may comprise a collection of the potential power supplies discussed above. Moreover, it may be possible to provide a capacitor or super-capacitor that is charged by an RF field generated by the reader **104**, thereby enabling the reader-enhancing device **204** to begin operating when a RF field is initially generated by the reader **104** and continue operating after the reader **104** has stopped generated by the RF field.

With reference now to FIG. **6**, a second exemplary physical configuration of the reader **104** and reader-enhancing device **204** will be described. In this particular configuration, the reader-enhancing device **204** has a surface area that is significantly smaller than the surface area of the reader's **104** face-plate. In such a configuration, the reader-enhancing device **204** may be affixed to the front, side, bottom, or top of the reader **104**. As one example, the reader-enhancing device **204** may correspond to a sticker that connects to the reader **104** with an adhesive. Although the reader-enhancing device **204** depicted in FIG. **6** is significantly smaller than the reader-enhancing device **204** depicted in FIG. **5**, one skilled in the art will appreciate that either reader-enhancing device **204** may comprise some or all of the components discussed in connection with FIG. **4**.

With reference now to FIG. **7**, a third exemplary physical configuration of the reader **104** and reader-enhancing device **204** will be described. This configuration depicts the scenario where the reader-enhancing device **204** covers at least a portion of the reader's **104** user interface **704**. As one example, the reader's **104** user interface **704** may correspond to an LED, collection of LEDs, buzzer, speaker, or the like and may be similar or identical to user interface **376**. The reader-enhancing device **204** is provided with a user interface via **708** which enables a user to interact with the user interface **704** of the reader **104**. In some embodiments, the user interface via **708** comprises a void or hole in the reader-enhancing device **204** which enables unobstructed physical access to the user interface **704**. In some embodiments, the user interface via **708** comprises fibers or similar optical components (e.g., lenses, mirrors, reflective coatings in the inner surface of the via **708**, etc.) which carry light generated by the user interface **704** to the outer surface of the reader-enhancing device **204**.

In some embodiments, the via **708** is not actually a hole or void but instead comprises a photo detector or microphone and an LED or buzzer. The photo detector or microphone may be provided on the surface of the reader-enhancing device **204** which is proximate to the reader **104**. The LED or buzzer may be provided on the opposite surface of the reader-enhancing device **204** which faces away from the reader **104**. The photo detector or microphone may be connected to the LED or buzzer thereby enabling the via **708** to transfer outputs of the user interface **704** to the exposed surface of the reader-enhancing device **204**.

Although the user interface **704** has been primarily described as a user output, one skilled in the art will appreciate that the user interface **704** may also comprise a user input and the configuration of the via **708** may be designed to accommodate the type of user input on the reader **104**.

With reference now to FIG. **8**, a first access control method will be described in accordance with at least some embodiments of the present invention. The method is initiated when input is received at the reader-enhancing device **204** (step **804**). The input received at the reader-enhancing device **204** may correspond to one or more of a credential input, a user-provided input, a biometric input, combinations thereof, or the like. The input, if received as a credential input, may be received from a first type of credential **112**, a second type of credential **208**, or any other type of credential. In some embodiments, the input received at the reader-enhancing device **204** does not necessarily have to be natively supported by the reader **104**. Exemplary inputs which may be received in this step include a credential input transmitted at 125 kHz, a credential input transmitted at 13.56 MHz, a credential input transmitted at some other carrier frequency, a credential input transmitted via infrared light, a credential input received with machine vision, a credential input transmitted via a contact-based medium (e.g., magnetic stripe, Wiegand card, etc.), or the like.

Upon receiving the input, the reader-enhancing device **204** invokes the authentication module **336** to analyze the input (step **808**) and determine if the received input corresponds to a valid input (step **812**). In this step, the authentication module **336** may compare the received input with one or more valid credential entries in the authentication data **340** to determine if the received input corresponds to a valid input. Rather than actually analyzing the content of the received input, the authentication module **336** may simply analyze the format and other characteristics of the received input and compare the format and characteristics with expected or acceptable formats or characteristics. If the received input has an expected format and/or characteristics, then the received input may be deemed valid. If the received input is not in an expected format or does not have expected characteristics (e.g., the received input has one or more of an unexpected carrier frequency, unexpected message format, unexpected protocol, unexpected data format, unexpected data field, etc.), then the received input may be determined to be invalid.

If the received input is determined to be invalid, then the method proceeds with the reader-enhancing device **204** performing one or more actions consistent with detecting an invalid input (step **816**). As one example, the reader-enhancing device **204** may take no action. As another example, the reader-enhancing device **204** may invoke the tamper detection module **332** to implement one or more actions responsive to detecting a potential attack on the reader **104** or reader-enhancing device **204**. For instance, the tamper detection module **332** may delay the responsiveness of the reader-enhancing device **204**, temporarily disable the reader-enhancing device **204**, temporarily disable the reader **104**, begin generating a jamming signal, erase sensitive data such as encryption keys, emulation templates **328**, configuration data **352**, authentication data **340**, etc. from memory **304**, set a flag in a non-volatile securely-stored memory location of the reader-enhancing device **204** which causes the reader-enhancing device **204** to become inoperable, and the like.

If, however, the authentication module **336** determines that the received input is valid, then the method continues with the communication module **316** determining if the received input needs to be reformatted such that it can be transmitted to the reader **104** (step **820**). Specifically, if the reader **104** is only capable of reading 125 kHz credentials and the input was received from a 13.56 MHz credential, then the reader-enhancing device **204** may need to alter the data format to comply with the limitations of the reader **104**. Conversely, if the received input was a user-provided input (e.g., PIN, password, biometric data, etc.), and the reader **104** is only configured to handle credential inputs, then the user-provided input may be reformatted as a credential input. If the query of step **820** is answered negatively (i.e., the received input is natively readable by the reader **104**), then the received input is simply forwarded to the reader **104** in its original format (step **824**).

If, on the other hand, the received input cannot be natively processed by the reader **104**, then the emulation module **312** and/or communication module **316** may be invoked to determine an appropriate output data format that is compliant with the limitations of the reader **104** (step **828**). Such a determination may be made by analyzing the configuration data **352** to determine the operating characteristics of the reader **104**.

Once the appropriate output data format is determined, the method continues with the communication module **316** and/or emulation module **312** altering the received input data into the appropriate format (step **832**) and providing the altered data to the reader **104** (step **836**). This particular access control method enables a reader-enhancing device **204** to act as a conduit between a credential **112**, **208** and the reader **104** for inputs that are natively supported by the reader **104** as well as a translator for inputs that are not natively supported by the reader **104**.

With reference now to FIG. **9**, details of a second access control method will be described in accordance with embodiments of the present disclosure. Similar to the first access control method, the second access control method is initiated when input is received at the reader-enhancing device **204** (step **904**). The method continues by invoking the authentication module **336** to analyze the received input (step **908**) and determine if the received input corresponds to a valid input (step **912**). In some embodiments, the authentication module **336** analyzes the data contained in the received input. In some embodiments, the authentication module **336** analyzes characteristics of the received input. In some embodiments, the authentication module **336** analyzes the format of the received input.

If the received input is determined to be invalid, the reader-enhancing device **204** performs one or more actions consistent with detecting an invalid input (step **916**). If, however, the received input is determined to be valid, the emulation module **312** is invoked to emulate a valid credential output that can be read and processed by the reader **104** (step **920**). In some embodiments, the received input may correspond to a valid 13.56 MHz credential input and the emulation module **312** may emulate a valid 125 kHz credential input for the reader **104** by determining a valid credential input from the emulation templates **328** and formatting the valid credential input for transmission via a 125 kHz carrier frequency. In some embodiments, the received input may correspond to a valid 125 kHz credential input and the emulation module **312** may emulate a valid 13.56 MHz credential input for the reader **104** by determining a valid credential input from the emulation templates **328** and formatting the valid credential input for transmission via the 13.56 MHz carrier frequency. In some embodiments, the received input may correspond to a valid user-provided input and the emulation module **312** may emulate a valid credential input in a format that can be processed by the communication module **420** of the reader **104**.

In this particular access control method, it is not necessary that the data received at the reader-enhancing device **204** be the same data provided to the reader **104**. For example, the data received at the reader-enhancing device **204** may correspond to first credential data (e.g., a first site code, a first card ID, a first user ID, a first manufacturer ID, a first key, etc.). If the data received at the reader-enhancing device **204** is determined to be valid by, for example, comparing the data with the authentication data **340**, then the emulation module **312** may generate a message for the reader **104** that contains valid second credential data (e.g., a second site code, a second card ID, a second user ID, a second manufacturer ID, a second key, etc.). The valid second credential data may be generated by retrieving a known valid credential input from the emulation templates **328**.

This particular access control method differs from the first access control method because rather than altering data received at the reader-enhancing device **204**, the emulation module **312** generates a credential input that is known, before its transmission, to be evaluated as valid by the reader **104** rather than simply translating or passing on inputs received from a credential.

With reference now to FIG. **10**, an exemplary tamper detection method will be described in accordance with at least some embodiments of the present disclosure. The tamper detection method is initiated when the reader-enhancing device begins monitoring for evidence of tamper (step **1004**). In some embodiments, the tamper detection module **332** is configured to periodically monitor the status of certain operating parameters of the reader-enhancing device **204** as well as the status any intrusion detectors **380**. In some embodiments, the tamper detection module **332** is configured to continuously monitor operating parameters of the reader-enhancing device **204** and/or the status of the intrusion detector **380**. The tamper detection module **332** may also analyze the behavior of the authentication module **336** to determine if any invalid inputs have been received, whether more than a predetermined number of invalid inputs have been received within a predetermined amount of time, and/or whether certain types of invalid inputs have been received.

Depending upon the results of the monitoring step, the tamper detection module **332** determines if evidence of tamper has been detected (step **1008**). If not, the method returns to step **1004**. If so, the method proceeds with the tamper detection module **332** determining one or more appropriate responses to the detection of tamper (step **1012**) and executed such responses (step **1016**).

In some embodiments, if evidence of tamper is detected, then the tamper detection module **332** may erase sensitive data including keys from memory **304** of the reader-enhancing device **204**. Moreover, a command may be transmitted to the reader **104** causing the reader **104** to erase any such sensitive data from its memory **408**.

Alternatively, or in addition, the reader-enhancing device **204** and/or reader **104** are disabled either temporarily (e.g., for a predetermined amount of time or until authorized personnel reboots the device) or permanently.

Alternatively, or in addition, the tamper detection module **332** sets a flag in a predetermined location of memory **304** which causes the reader-enhancing device **204** to become inoperable.

Alternatively, or in addition, the tamper detection module **332** may invoke the shielding module **348** to prevent the reader from reading credential input.

Alternatively, or in addition, a buzzer, alarm, or the like may be engaged to notify security personnel that tamper has been detected. Similarly, the tamper detection module **332** may generate one or more messages (e.g., email, Short Message Service (SMS), Multimedia Message Service (MMS), etc.) which are transmitted to communication devices associated with security personnel.

Referring now to FIG. **11**, an exemplary virtual credential generation method will be described in accordance with embodiments of the present disclosure. The method begins when the emulation module **312** determines whether to generate a virtual credential output (steps **1104** and **1108**).

In some embodiments, the reader-enhancing device **204** is configured to generate a virtual credential output without having read a credential or received any other type of input. Rather, the reader-enhancing device **204** is configured to generate a virtual credential output randomly, periodically, or semi-periodically, regardless of whether or not an external input has been received at the reader-enhancing device. Generation of a virtual credential output on a random, periodic, or semi-periodic basis helps increase the security of the reader-enhancing device **204** and reader **104** and further ensure that the connection between the two devices has not been tampered with.

In some embodiments, the reader-enhancing device **204** is configured to generate a virtual credential output when the tamper detection module **332** detects evidence of tamper. A virtual credential generated in response to such an occurrence may have a predetermined set of credential data that, when analyzed by the reader **104**, allows the reader **104** to determine that evidence of tamper has been detected. This enables the reader-enhancing device **204** to report evidence of tamper to the reader **104** via a virtual credential output. Accordingly, the reader **104** does not have to be modified to support a different communication protocol with the reader-enhancing device **204**. Instead, the reader-enhancing device **204** is configured to communicate with the reader **104** in a format understood by the reader **104**.

If the query of step **1108** is answered negatively, the method remains in the loop of steps **1104** and **1108**. If it is determined that it is time to generate a virtual credential output, then the emulation module **312** refers to the emulation templates **328** and generates a virtual credential output with the data contained in one or more fields of the emulation templates **328** (step **1112**). The generated virtual credential output is then transmitted to the reader **104** via the credential interface **384** where it is received at the reader's **104** credential interface **416**.

In some embodiments it may be desirable to encrypt or obfuscate the virtual credential output before it is transmitted to the reader **104**. In such embodiments, the encryption module **320** may be invoked to encrypt the virtual credential output generated by the emulation module **312** with an encryption key or obfuscate the virtual credential output according to a predetermined obfuscation algorithm before the virtual credential output is provided to the reader **104**.

In some embodiments, the virtual credential output may contain instructions which cause the reader **104** to alter its configurations. In particular, the virtual credential output may contain configuration data which reprograms one or more operating characteristics of the reader **104** to, hopefully, counteract possible attacks on the reader **104**. As one example, the virtual credential output may comprise configuration data which causes the reader **104** to alter its behavior such that it only readers credentials of a certain type and does not respond to any other type of input. By providing the reader-enhancing device **204** with these capabilities the reader **104** can be upgraded without replacing or upgrading any components of the reader **104** itself.

In the foregoing description, for the purposes of illustration, methods were described in a particular order. It should be appreciated that in alternate embodiments, the methods may be performed in a different order than that described. It should also be appreciated that the methods described above may be performed by hardware components or may be embodied in sequences of machine-executable instructions, which may be used to cause a machine, such as a general-purpose or special-purpose processor or logic circuits programmed with the instructions to perform the methods. These machine-executable instructions may be stored on one or more machine readable mediums, such as CD-ROMs or other type of optical disks, floppy diskettes, ROMs, RAMs, EPROMs, EEPROMs, magnetic or optical cards, flash memory, or other types of machine-readable mediums suitable for storing electronic instructions. Alternatively, the methods may be performed by a combination of hardware and software.

Specific details were given in the description to provide a thorough understanding of the embodiments. However, it will be understood by one of ordinary skill in the art that the embodiments may be practiced without these specific details. For example, circuits may be shown in block diagrams in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques may be shown without unnecessary detail in order to avoid obscuring the embodiments.

Also, it is noted that the embodiments were described as a process which is depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed, but could have additional steps not included in the figure. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to the calling function or the main function.

Furthermore, embodiments may be implemented by hardware, software, firmware, middleware, microcode, hardware description languages, or any combination thereof. When implemented in software, firmware, middleware or microcode, the program code or code segments to perform the necessary tasks may be stored in a machine readable medium such as storage medium. A processor(s) may perform the necessary tasks. A code segment may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

While illustrative embodiments of the disclosure have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art.

What is claimed is:

1. A method, comprising:

providing a reader-enhancing device within a read range of a reader, wherein the reader is natively configured to read a first type of credential;

configuring the reader-enhancing device such that an output of the reader enhancing device emulates the first type of credential so as to enable communications between the reader-enhancing device and the reader;

receiving input at the reader-enhancing device, the input received at the reader-enhancing device being different than an input received from the first type of credential; and

in response to receiving the input at the reader-enhancing device, generating, at the reader-enhancing device, an output which emulates the first type of credential thereby enabling the reader to respond to the input received at the reader-enhancing device, wherein the reader is not configured to read the input received at the reader-enhancing device.

2. The method of claim **1**, wherein the first type of credential comprises a 125 kHz credential and wherein the input received at the reader-enhancing device comprises one or more of credential input from a 13.56 MHz credential and user-provided input.

3. The method of claim **1**, wherein the reader-enhancing device comprises a power source that at least partially utilizes energy from an RF field generated by the reader.

4. The method of claim **3**, wherein the power source further comprises one or more of a batter, a capacitor, a super-capacitor, and a solar cell.

5. The method of claim **1**, wherein the reader-enhancing device is configured to memorize characteristics of the reader including one or more of the reader's frequency variation, power levels, polling rate, and timing so that the reader-enhancing device is configured to interface only with the reader having the memorized characteristics.

6. The method of claim **1**, further comprising:

operating the reader-enhancing device during a period of time when the reader is not generating an RF field.

7. The method of claim **1**, further comprising:

generating a virtual credential output at the reader-enhancing device; and

providing the virtual credential output to the reader, wherein the virtual credential output is provided in a format identical to a format used by the first type of credential.

8. The method of claim **7**, wherein the virtual credential output is generated in the absence of the reader-enhancing device receiving an external input.

9. The method of claim **7**, wherein the virtual credential output is generated in response to the reader-enhancing device detecting evidence of tamper with one or both of the reader and reader-enhancing device.

10. The method of claim **9**, wherein the virtual credential output contains configuration data which, when received by the reader, reprograms at least one characteristic of the reader includes one or more of the following: frequency variation, operating frequency, power levels, polling rate, timing characteristics, reader model number, firmware version, reader identifier, and data which describes the reader.

11. The method of claim **7**, wherein the virtual credential output contains one or more of cryptographic data, encryption keys, and random number seeds.

12. The method of claim **1**, further comprising:

changing one or more operating characteristics of the reader-enhancing device by establishing a communication channel with the reader-enhancing device and providing the reader-enhancing device with one or more commands via the communication channel which causes the reader-enhancing device to change one or more of its operating characteristics; and

wherein the reader-enhancing device, prior to changing one or more of its operating characterizes, is absent operating characteristics enabling the reader-enhancing device to perform at least one of providing the output and receiving the input.

13. The method of claim **1**, wherein the reader-enhancing device is configured to reject credentials having a location identifier, company identifier, or site code different from a predetermined location identifier, a predetermined company identifier, or a predetermined site code, respectively.

14. The method of claim **1**, wherein the reader-enhancing device is configured to receive a user-provided input and based on the user-provided input generate an output which emulates the first type of credential.

15. The method of claim **14**, wherein the output generated based on the user-provided input comprises an alteration of the user-provided input into a format used by the first type of credential.

16. The method of claim **14**, wherein the output generated based on the user-provided input comprises an emulation template that is known by the reader-enhancing device, before transmission of the output to the reader, to be evaluated as valid by the reader.

17. A non-transitory computer-readable medium comprising processor-executable instructions that, when executed by a processor of the terminal, perform the method of claim **1**.

18. A method, comprising:

securing a reader-enhancing device on or within read range of a reader, wherein the reader is natively configured to only process data from a first type of credential, wherein the reader-enhancing device is configured to process one or both of data from a second type of credential and user-provided data;

receiving input at the reader-enhancing device;

analyzing the input received at the reader-enhancing device;

determining that the input is not in a format used by the first type of credential; and

generating, at the reader-enhancing device, an output which emulates the first type of credential thereby enabling the reader to respond to the input received at the reader-enhancing device, wherein the reader is not configured to read the input received at the reader-enhancing device.

19. The method of claim **18**, wherein the reader-enhancing device comprises a sticker that is secured to the reader with an adhesive.

20. The method of claim **18**, wherein the reader-enhancing device comprises a face-plate that is secured to the reader with one or more connectors.

21. A reader-enhancing device operating in cooperation with a reader that is configured to only process data from a first type of credential, the reader-enhancing device comprising:

memory including an emulation module configured to generate an output which emulates the first type of credential when the reader-enhancing device receives an input that is not in a format used by the first type of credential, wherein the output generated by the emulation module enables the reader to respond to the input even though the input is not in a format used by the first type of credential or a format that is readable by the reader; and

a processor configured to execute the emulation module.

22. The reader-enhancing device of claim **21**, wherein the reader-enhancing device comprises a via which enables a user to access a user interface of the reader even though the reader-enhancing device is positioned over a surface of the reader which comprises the user interface.

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