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(54) SYSTEM AND METHOD FOR AUTHENTICATION VIA A PROXIMATE DEVICE

(76) Inventors: **Mark Buer**, Gilbert, AZ (US); **Ed Frank**, Atherton, CA (US)

Correspondence Address:
CHRISTIE, PARKER & HALE, LLP
PO BOX 7068
PASADENA, CA 91109-7068 (US)

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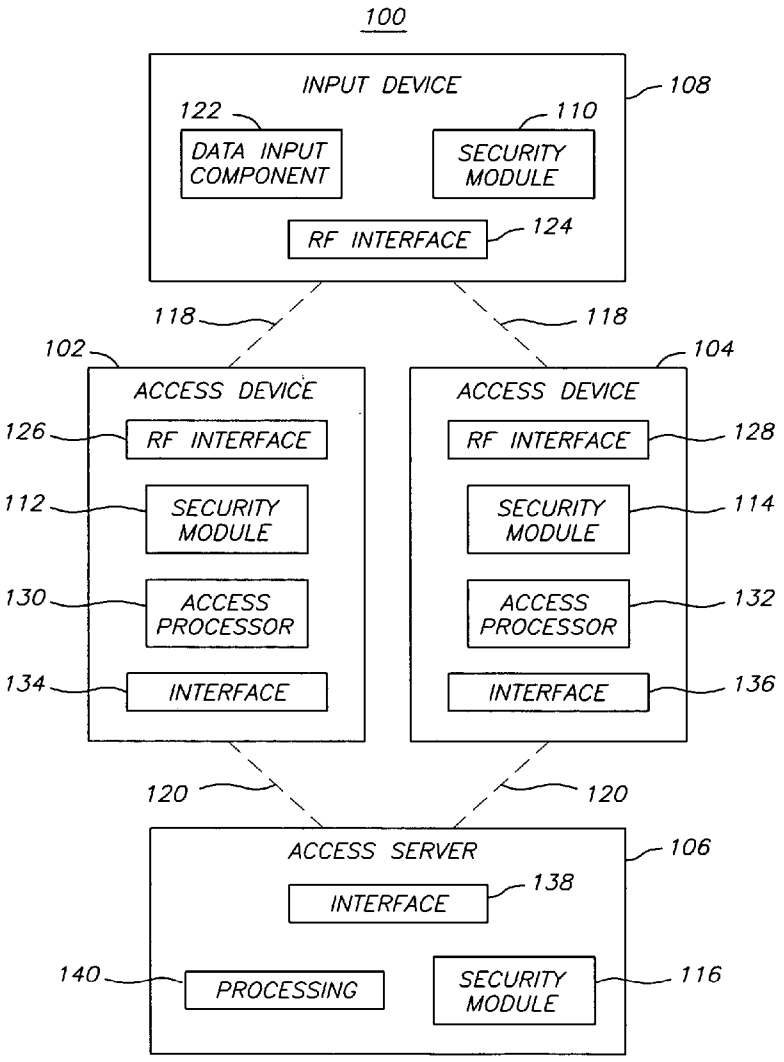
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(57) **ABSTRACT**

Techniques are provided to authenticate components in a system. Users may enter credentials into an input device and the credentials may be authenticated and/or securely transmitted to the components. The components may then provide the credentials to a server in the system. Strong authentication may thus be provided to the effect that credentials associated with specific users have been received from specific components in the system. The server may then enable the components to access selected services.



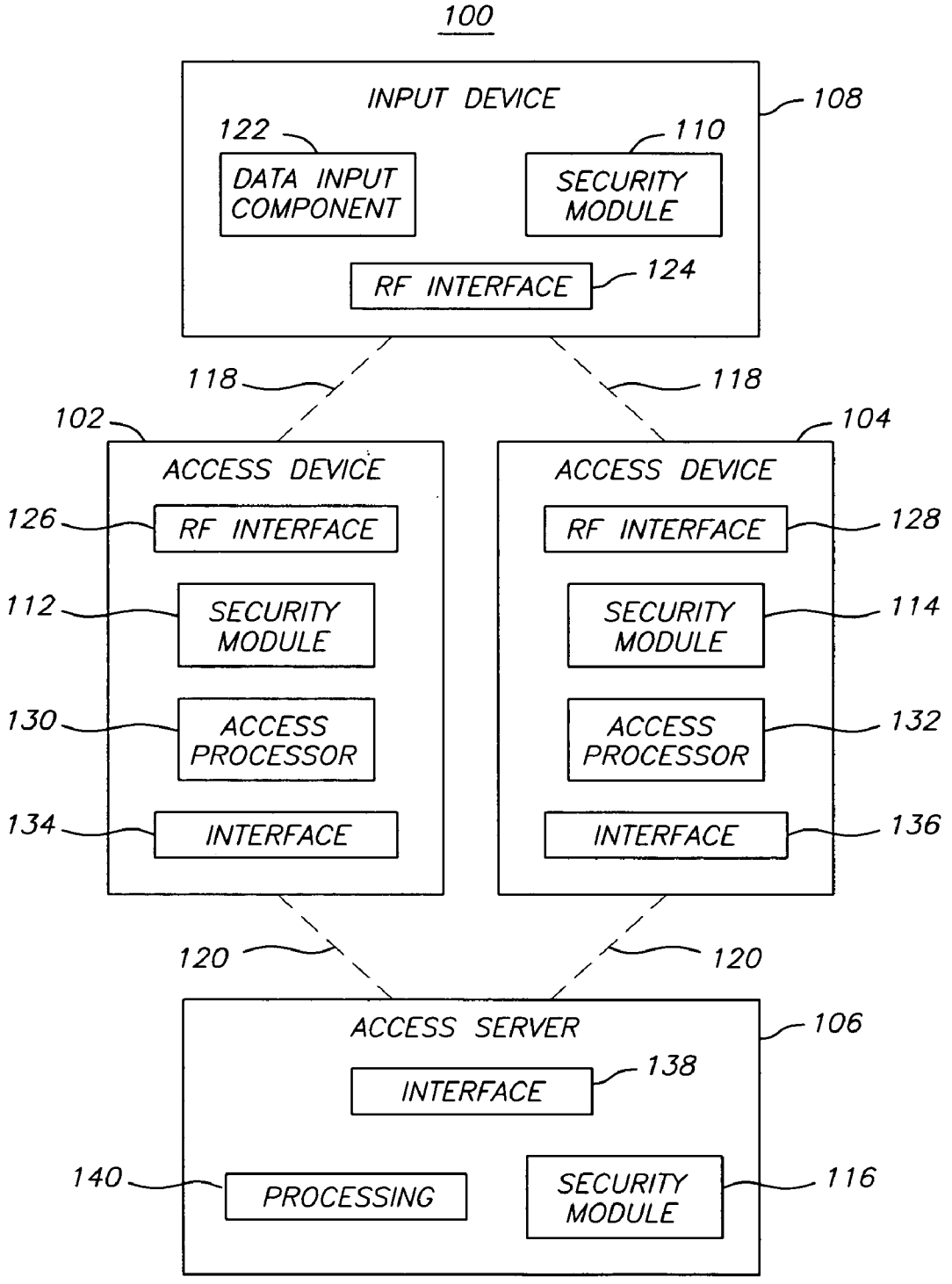

100
INPUT DEVICE
108
122
DATA INPUT COMPONENT
110
SECURITY MODULE
RF INTERFACE
124
118
118
102
ACCESS DEVICE
104
ACCESS DEVICE
126
RF INTERFACE
RF INTERFACE
128
112
SECURITY MODULE
SECURITY MODULE
114
130
ACCESS PROCESSOR
ACCESS PROCESSOR
132
134
INTERFACE
INTERFACE
136
120
120
ACCESS SERVER
106
INTERFACE
138
140
PROCESSING
SECURITY MODULE
116

FIG. 1

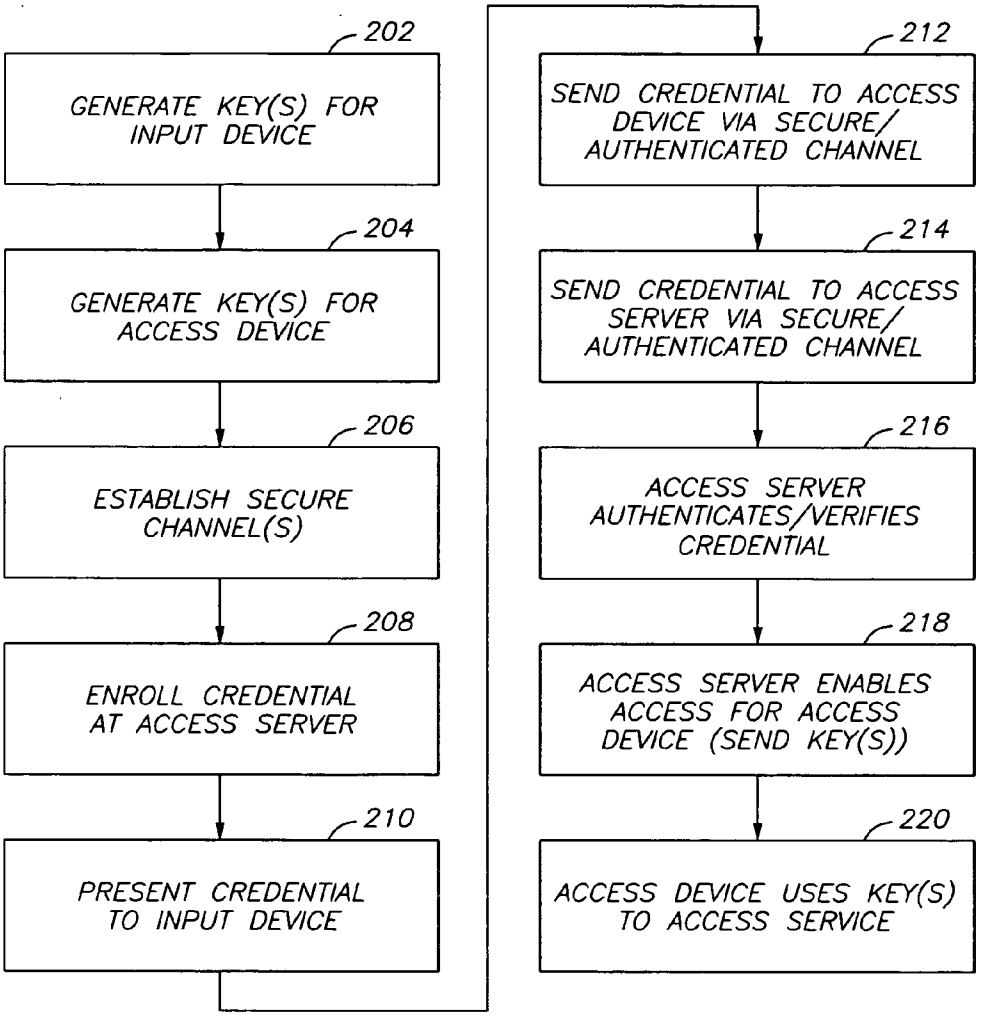

202
GENERATE KEY(S) FOR INPUT DEVICE
204
GENERATE KEY(S) FOR ACCESS DEVICE
206
ESTABLISH SECURE CHANNEL(S)
208
ENROLL CREDENTIAL AT ACCESS SERVER
210
PRESENT CREDENTIAL TO INPUT DEVICE
212
SEND CREDENTIAL TO ACCESS DEVICE VIA SECURE/ AUTHENTICATED CHANNEL
214
SEND CREDENTIAL TO ACCESS SERVER VIA SECURE/ AUTHENTICATED CHANNEL
216
ACCESS SERVER AUTHENTICATES/VERIFIES CREDENTIAL
218
ACCESS SERVER ENABLES ACCESS FOR ACCESS DEVICE (SEND KEY(S))
220
ACCESS DEVICE USES KEY(S) TO ACCESS SERVICE

FIG. 2

FIG. 3

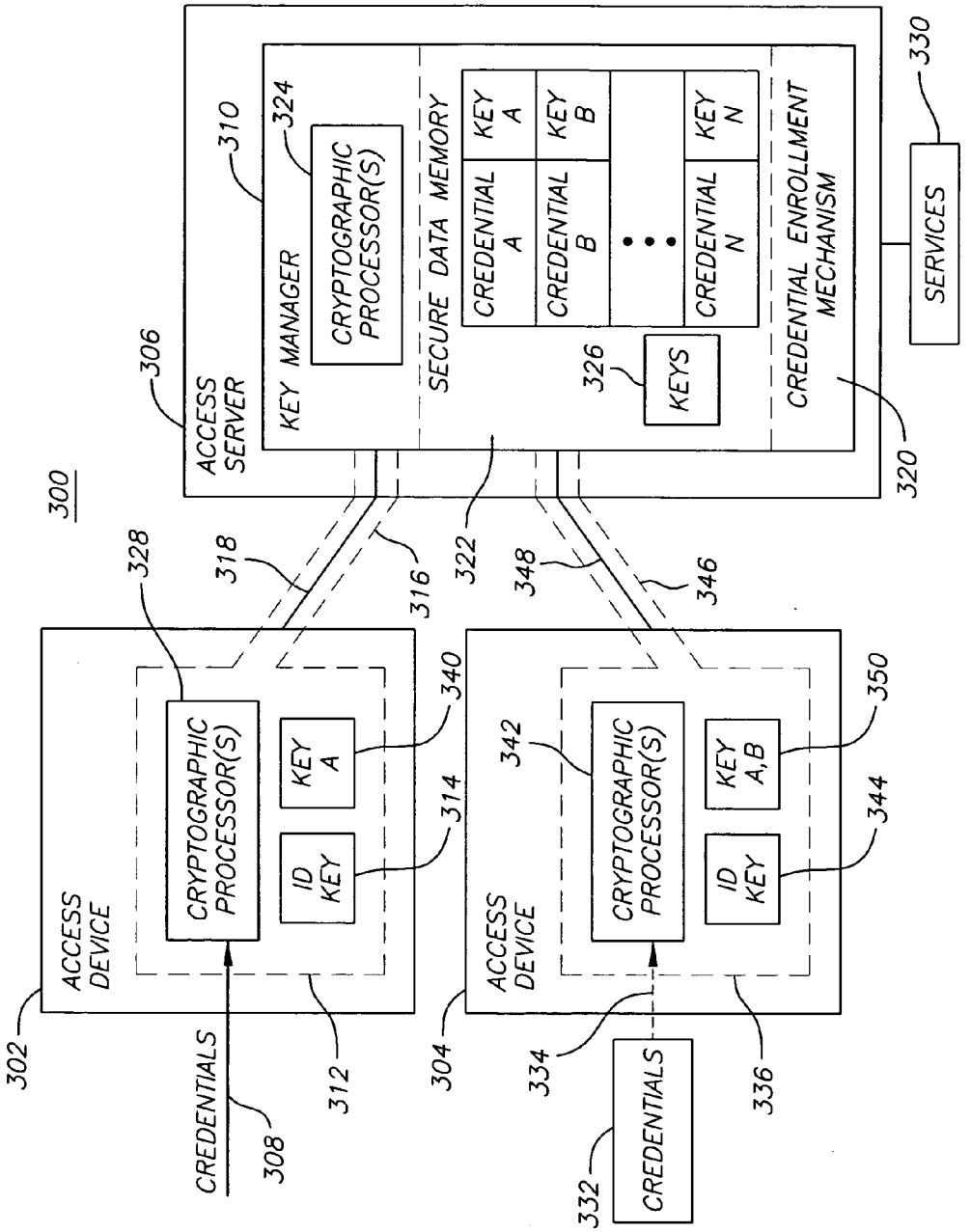
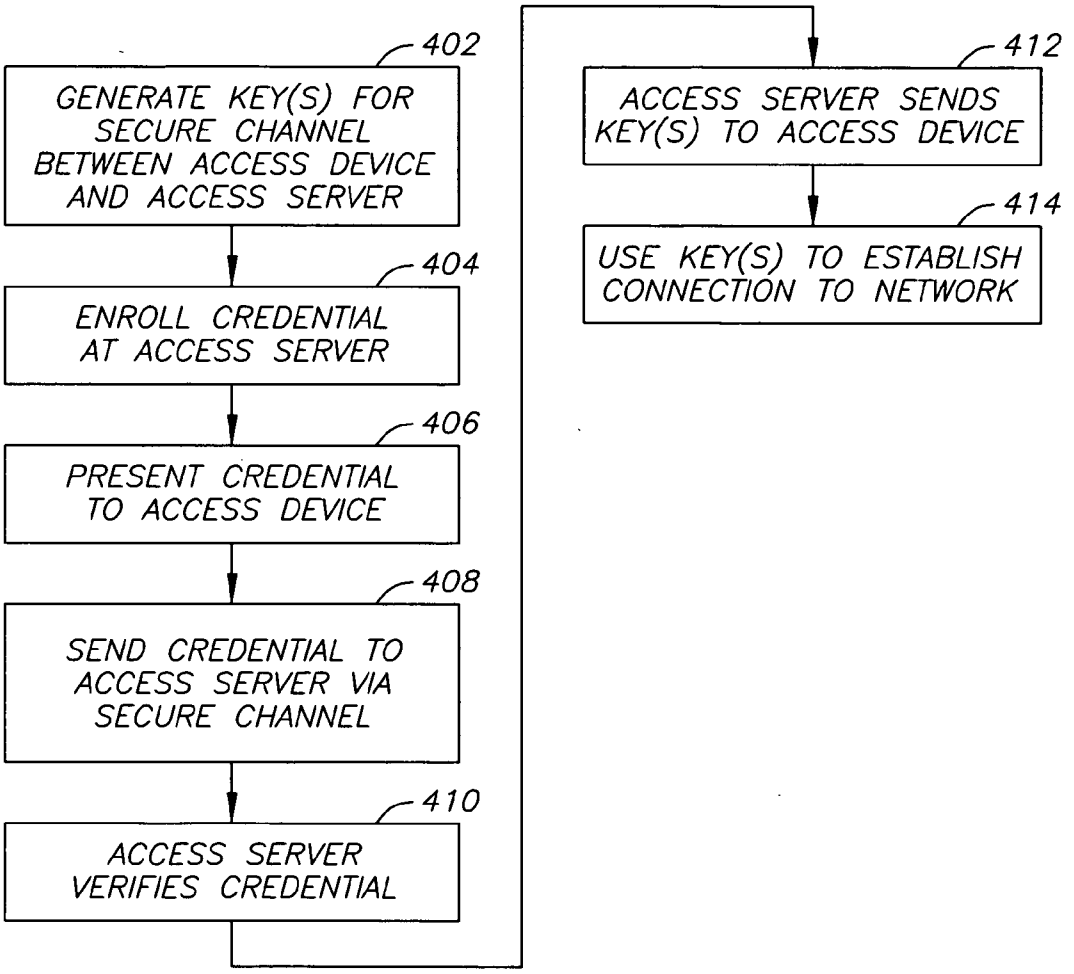

300
ACCESS SERVER
306
KEY MANAGER
310
CRYPTOGRAPHIC PROCESSOR(S)
324
SECURE DATA MEMORY
CREDENTIAL A
KEY A
CREDENTIAL B
KEY B
CREDENTIAL N
KEY N
326
KEYS
CREDENTIAL ENROLLMENT MECHANISM
320
SERVICES
330
318
316
322
348
346
328
340
342
350
314
344
ACCESS DEVICE
302
CRYPTOGRAPHIC PROCESSOR(S)
KEY A
ID KEY
ACCESS DEVICE
304
CRYPTOGRAPHIC PROCESSOR(S)
KEY A,B
ID KEY
CREDENTIALS
308
312
334
336
CREDENTIALS
332

FIG. 4


402
GENERATE KEY(S) FOR SECURE CHANNEL BETWEEN ACCESS DEVICE AND ACCESS SERVER
404
ENROLL CREDENTIAL AT ACCESS SERVER
406
PRESENT CREDENTIAL TO ACCESS DEVICE
408
SEND CREDENTIAL TO ACCESS SERVER VIA SECURE CHANNEL
410
ACCESS SERVER VERIFIES CREDENTIAL
412
ACCESS SERVER SENDS KEY(S) TO ACCESS DEVICE
414
USE KEY(S) TO ESTABLISH CONNECTION TO NETWORK

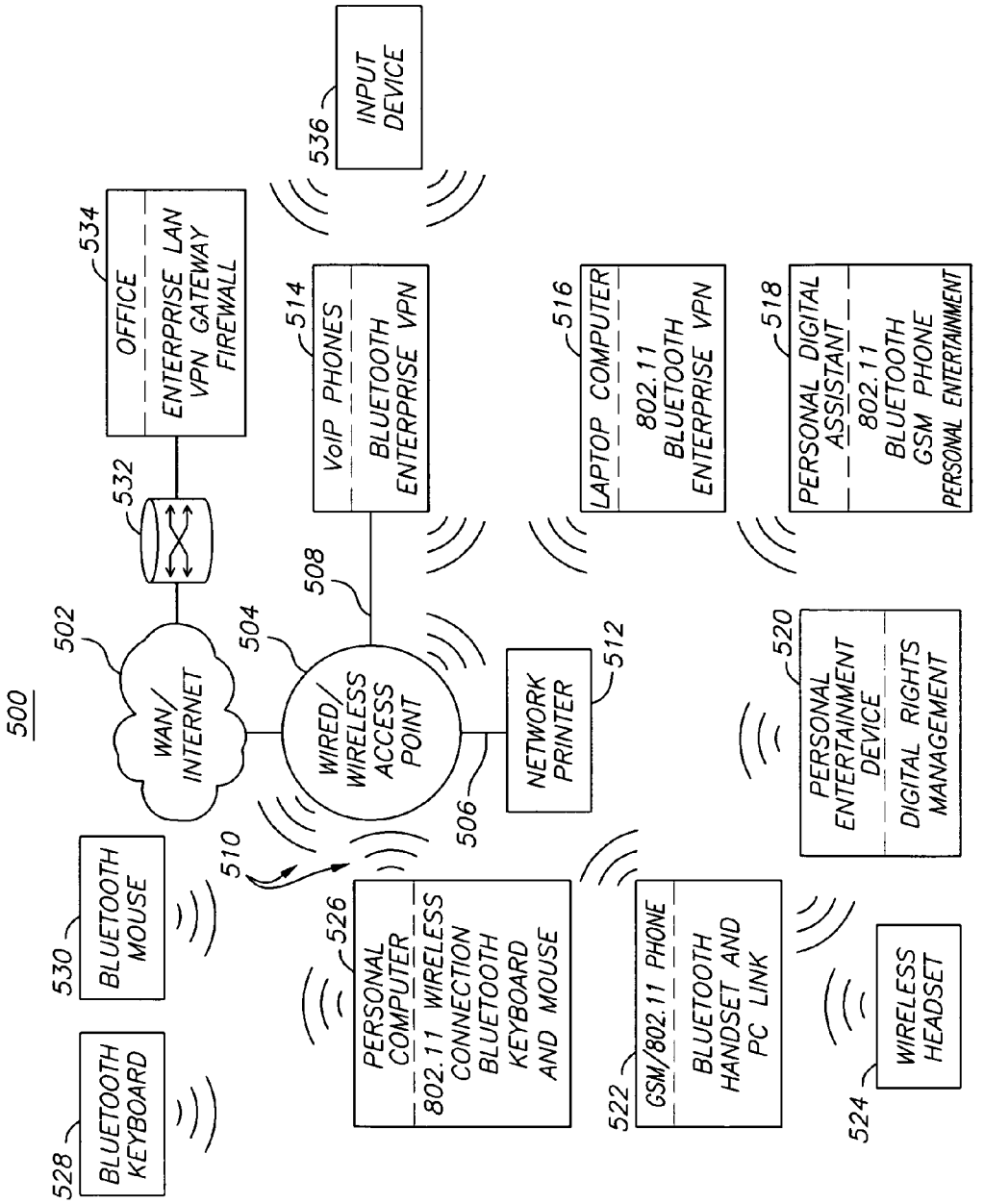

500
WAN/ INTERNET
502
WIRED/ WIRELESS ACCESS POINT
504
506
508
510
NETWORK PRINTER
512
OFFICE
ENTERPRISE LAN
VPN GATEWAY
FIREWALL
534
532
INPUT DEVICE
536
VoIP PHONES
BLUETOOTH
ENTERPRISE VPN
514
LAPTOP COMPUTER
802.11
BLUETOOTH
ENTERPRISE VPN
516
PERSONAL DIGITAL ASSISTANT
802.11
BLUETOOTH
GSM PHONE
PERSONAL ENTERTAINMENT
518
PERSONAL ENTERTAINMENT DEVICE
DIGITAL RIGHTS MANAGEMENT
520
BLUETOOTH MOUSE
530
BLUETOOTH KEYBOARD
528
PERSONAL COMPUTER
802.11 WIRELESS
CONNECTION
BLUETOOTH
KEYBOARD
AND MOUSE
526
GSM/802.11 PHONE
BLUETOOTH
HANDSET AND
PC LINK
522
WIRELESS HEADSET
524

FIG. 5

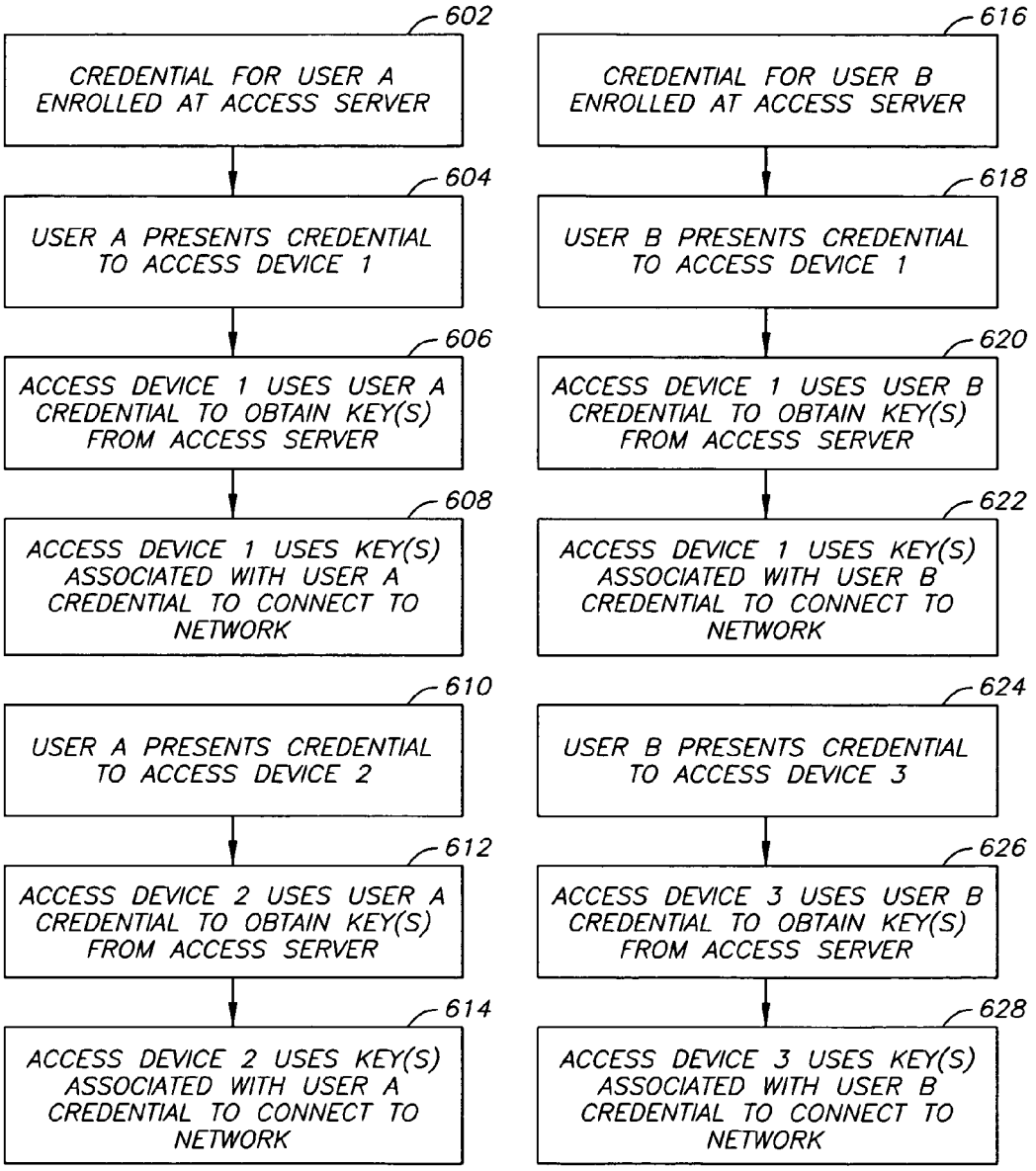

602
CREDENTIAL FOR USER A ENROLLED AT ACCESS SERVER
604
USER A PRESENTS CREDENTIAL TO ACCESS DEVICE 1
606
ACCESS DEVICE 1 USES USER A CREDENTIAL TO OBTAIN KEY(S) FROM ACCESS SERVER
608
ACCESS DEVICE 1 USES KEY(S) ASSOCIATED WITH USER A CREDENTIAL TO CONNECT TO NETWORK
610
USER A PRESENTS CREDENTIAL TO ACCESS DEVICE 2
612
ACCESS DEVICE 2 USES USER A CREDENTIAL TO OBTAIN KEY(S) FROM ACCESS SERVER
614
ACCESS DEVICE 2 USES KEY(S) ASSOCIATED WITH USER A CREDENTIAL TO CONNECT TO NETWORK
616
CREDENTIAL FOR USER B ENROLLED AT ACCESS SERVER
618
USER B PRESENTS CREDENTIAL TO ACCESS DEVICE 1
620
ACCESS DEVICE 1 USES USER B CREDENTIAL TO OBTAIN KEY(S) FROM ACCESS SERVER
622
ACCESS DEVICE 1 USES KEY(S) ASSOCIATED WITH USER B CREDENTIAL TO CONNECT TO NETWORK
624
USER B PRESENTS CREDENTIAL TO ACCESS DEVICE 3
626
ACCESS DEVICE 3 USES USER B CREDENTIAL TO OBTAIN KEY(S) FROM ACCESS SERVER
628
ACCESS DEVICE 3 USES KEY(S) ASSOCIATED WITH USER B CREDENTIAL TO CONNECT TO NETWORK

FIG. 6

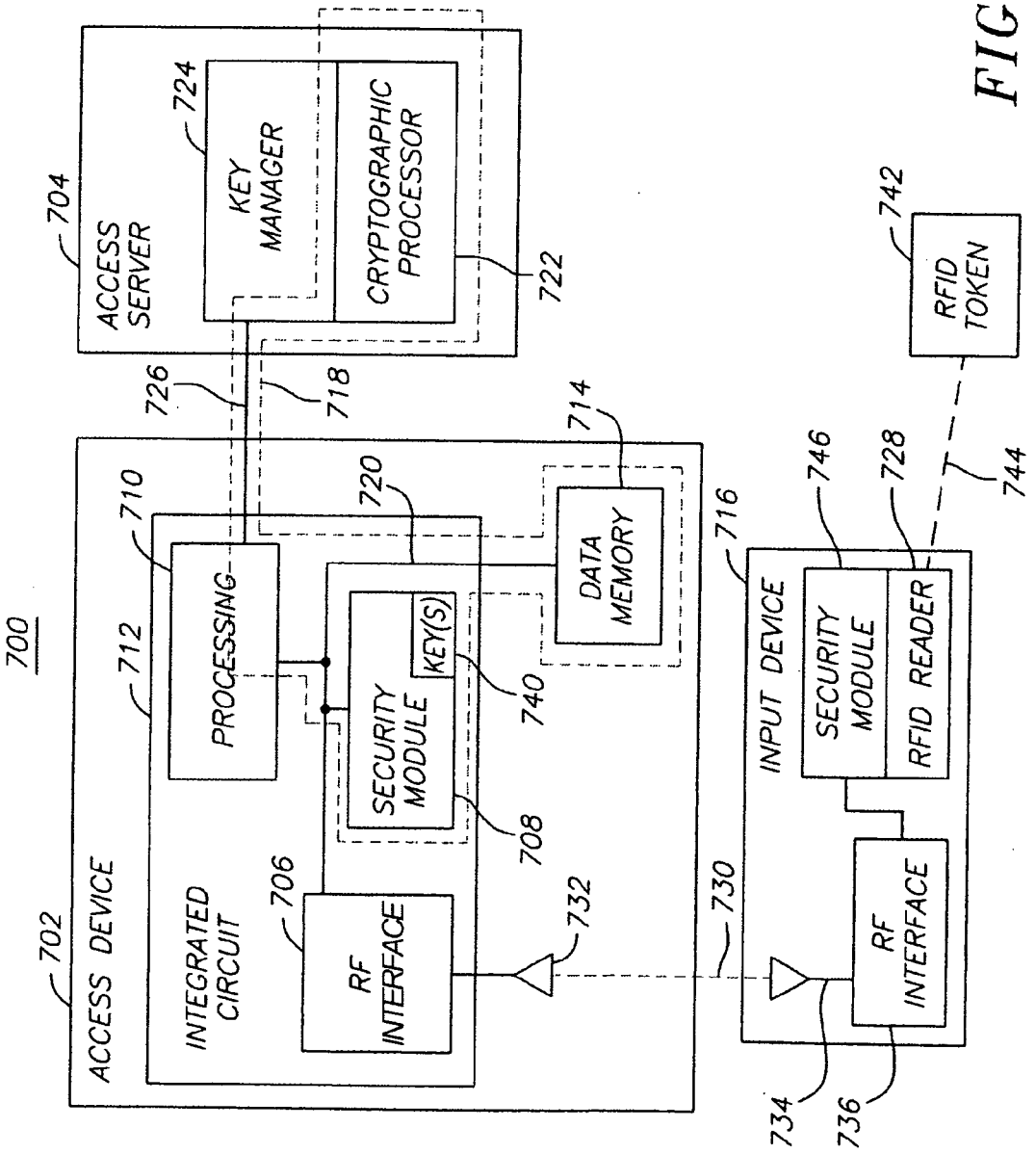

700
ACCESS DEVICE
702
INTEGRATED CIRCUIT
PROCESSING
712
710
SECURITY MODULE
KEY(S)
740
708
RF INTERFACE
706
732
DATA MEMORY
714
720
726
718
730
ACCESS SERVER
704
KEY MANAGER
724
CRYPTOGRAPHIC PROCESSOR
722
INPUT DEVICE
716
SECURITY MODULE
746
RFID READER
728
RF INTERFACE
734
736
RFID TOKEN
742
744

FIG. 7

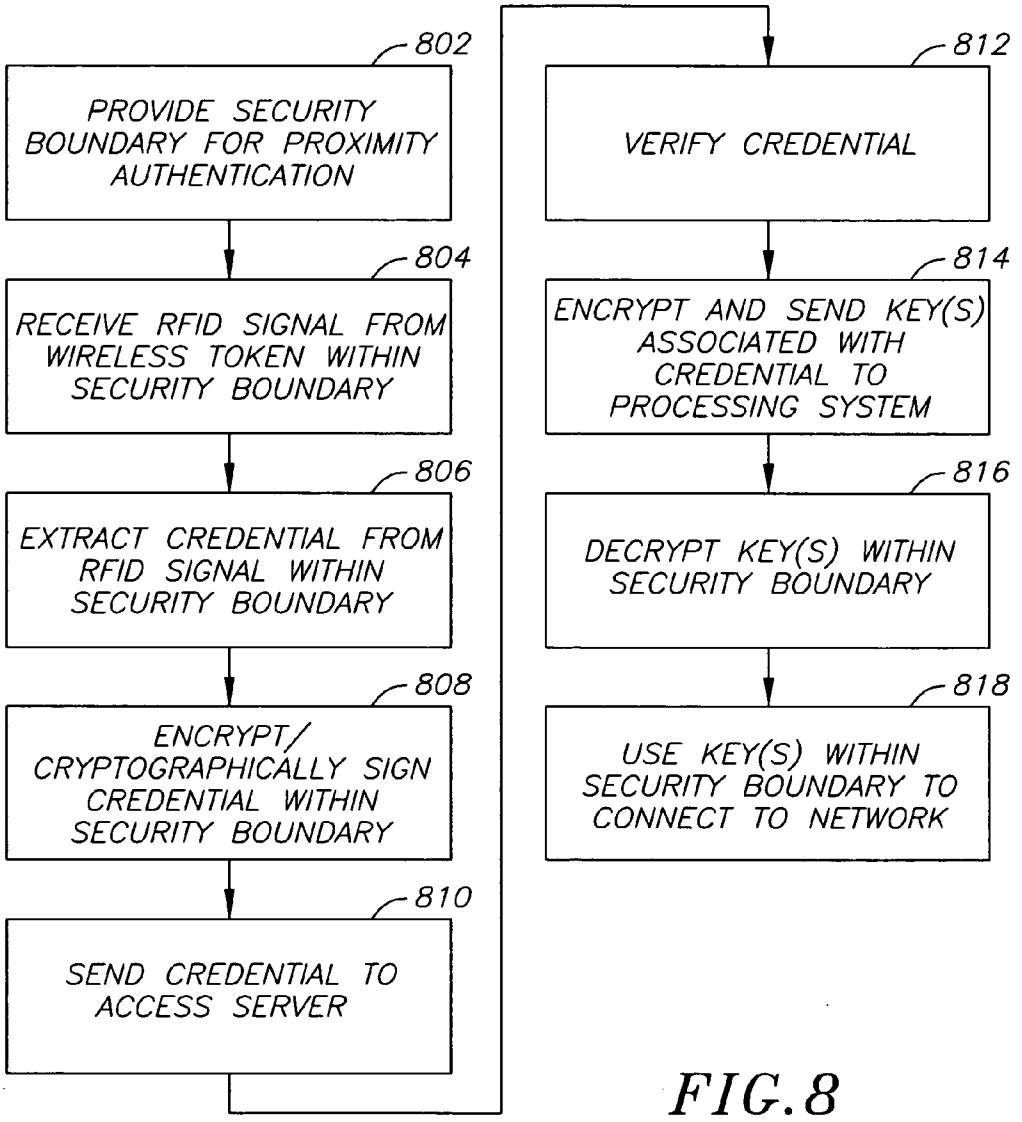
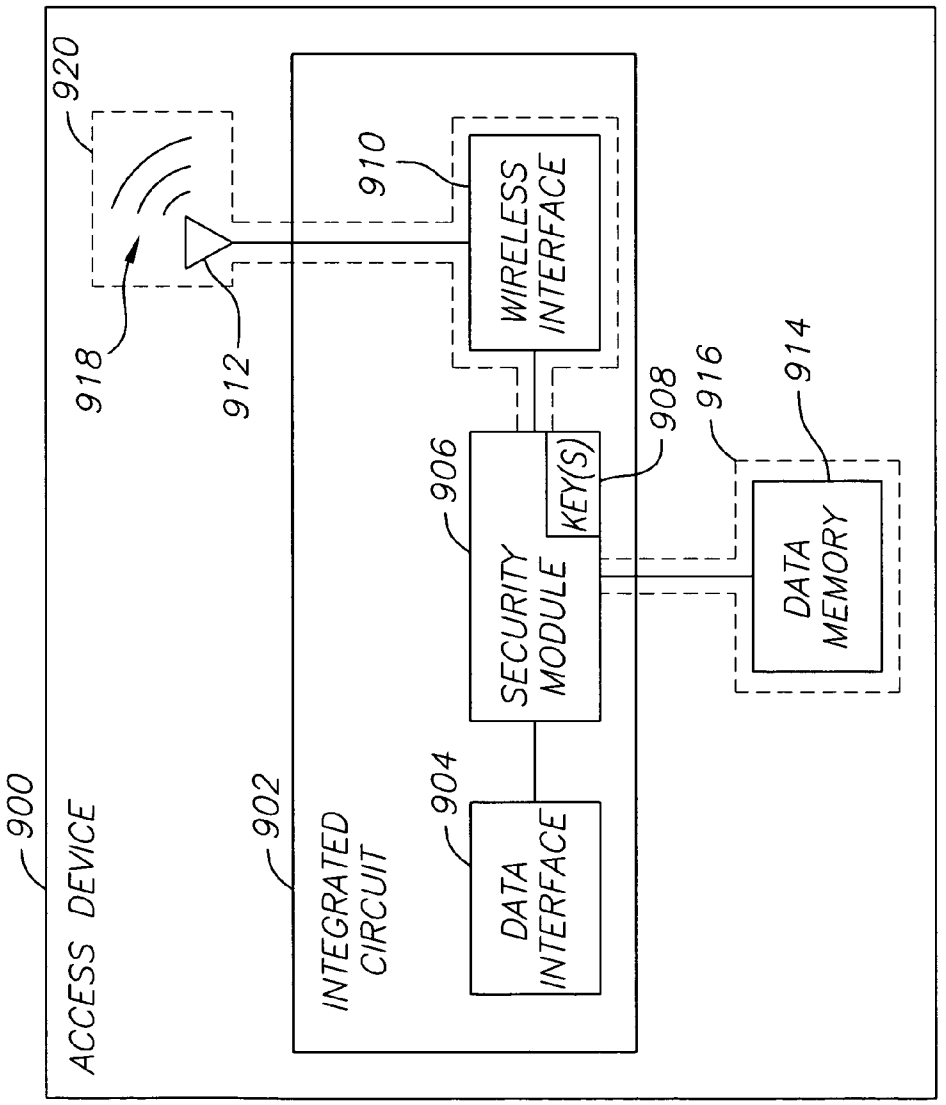

802
PROVIDE SECURITY BOUNDARY FOR PROXIMITY AUTHENTICATION
804
RECEIVE RFID SIGNAL FROM WIRELESS TOKEN WITHIN SECURITY BOUNDARY
806
EXTRACT CREDENTIAL FROM RFID SIGNAL WITHIN SECURITY BOUNDARY
808
ENCRYPT/ CRYPTOGRAPHICALLY SIGN CREDENTIAL WITHIN SECURITY BOUNDARY
810
SEND CREDENTIAL TO ACCESS SERVER
812
VERIFY CREDENTIAL
814
ENCRYPT AND SEND KEY(S) ASSOCIATED WITH CREDENTIAL TO PROCESSING SYSTEM
816
DECRYPT KEY(S) WITHIN SECURITY BOUNDARY
818
USE KEY(S) WITHIN SECURITY BOUNDARY TO CONNECT TO NETWORK

FIG. 8

FIG. 9


900
ACCESS DEVICE
902
INTEGRATED CIRCUIT
904
DATA INTERFACE
906
SECURITY MODULE
KEY(S)
908
910
WIRELESS INTERFACE
912
914
DATA MEMORY
916
918
920

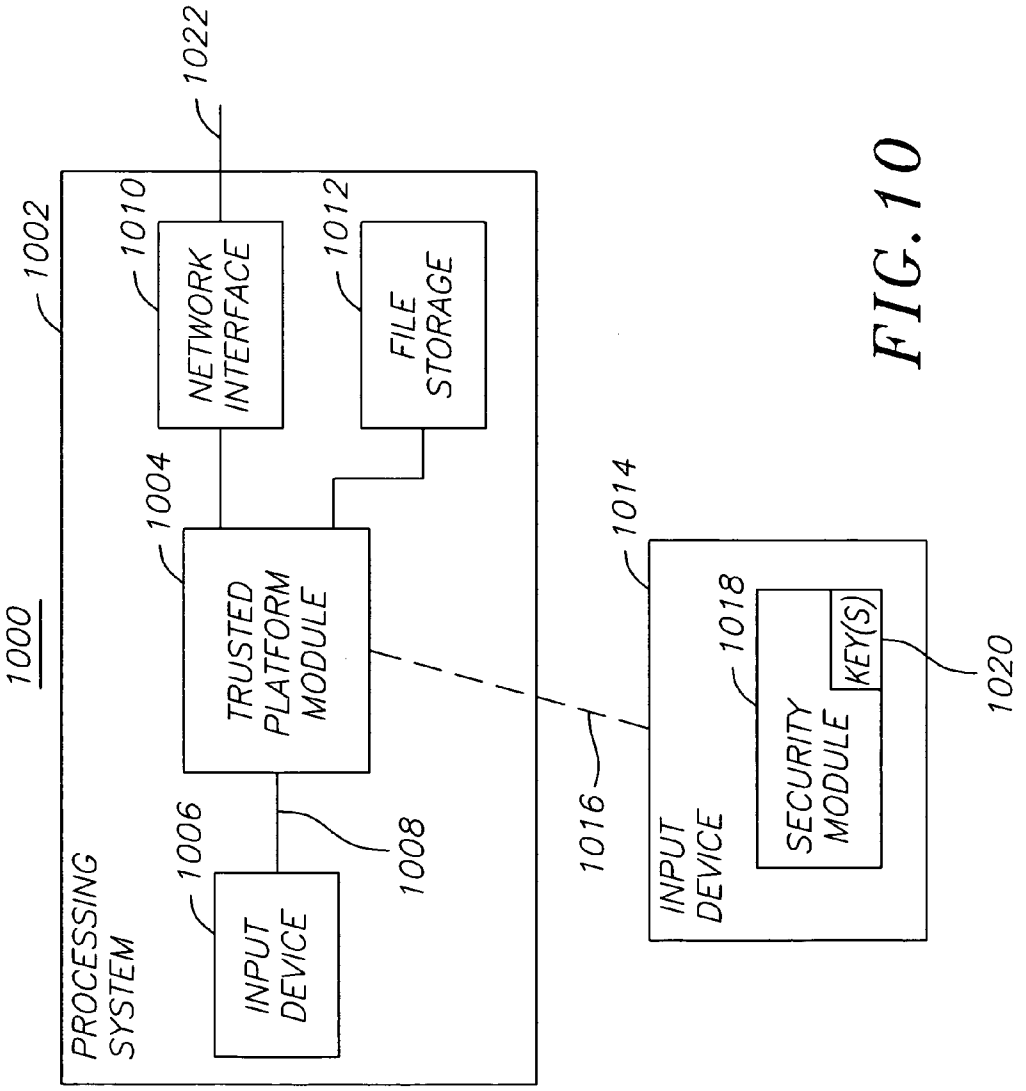
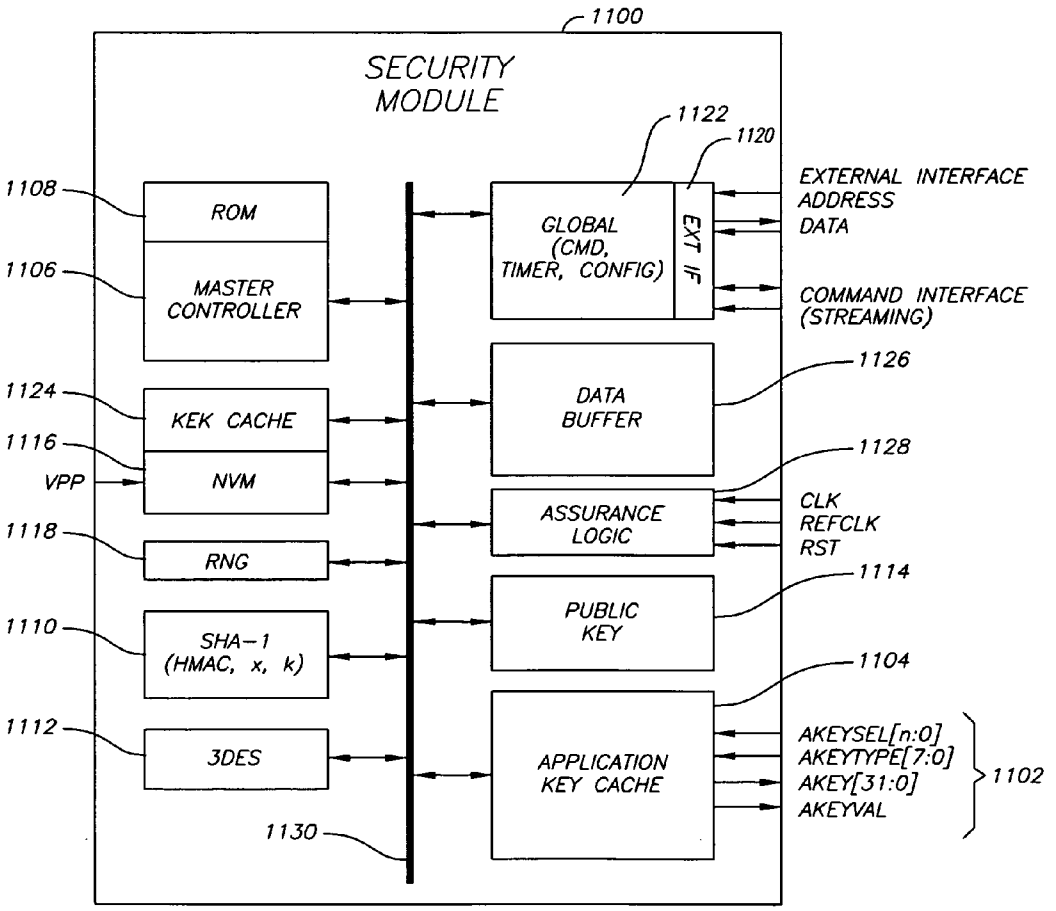

1000
1002
PROCESSING SYSTEM
1004
TRUSTED PLATFORM MODULE
1006
INPUT DEVICE
1008
1010
NETWORK INTERFACE
1012
FILE STORAGE
1014
INPUT DEVICE
1016
1018
SECURITY MODULE
KEY(S)
1020
1022

FIG. 10

FIG. 11


1100
SECURITY MODULE
1122
1120
1108
ROM
1106
MASTER CONTROLLER
GLOBAL (CMD, TIMER, CONFIG)
EXT IF
EXTERNAL INTERFACE
ADDRESS
DATA
COMMAND INTERFACE (STREAMING)
1124
KEK CACHE
1116
VPP
NVM
DATA BUFFER
1126
1128
ASSURANCE LOGIC
CLK
REFCLK
RST
1118
RNG
1114
PUBLIC KEY
1110
SHA-1 (HMAC, x, k)
1104
1112
3DES
APPLICATION KEY CACHE
AKEYSEL[n:0]
AKEYTYPE[7:0]
AKEY[31:0]
AKEYVAL
1102
1130

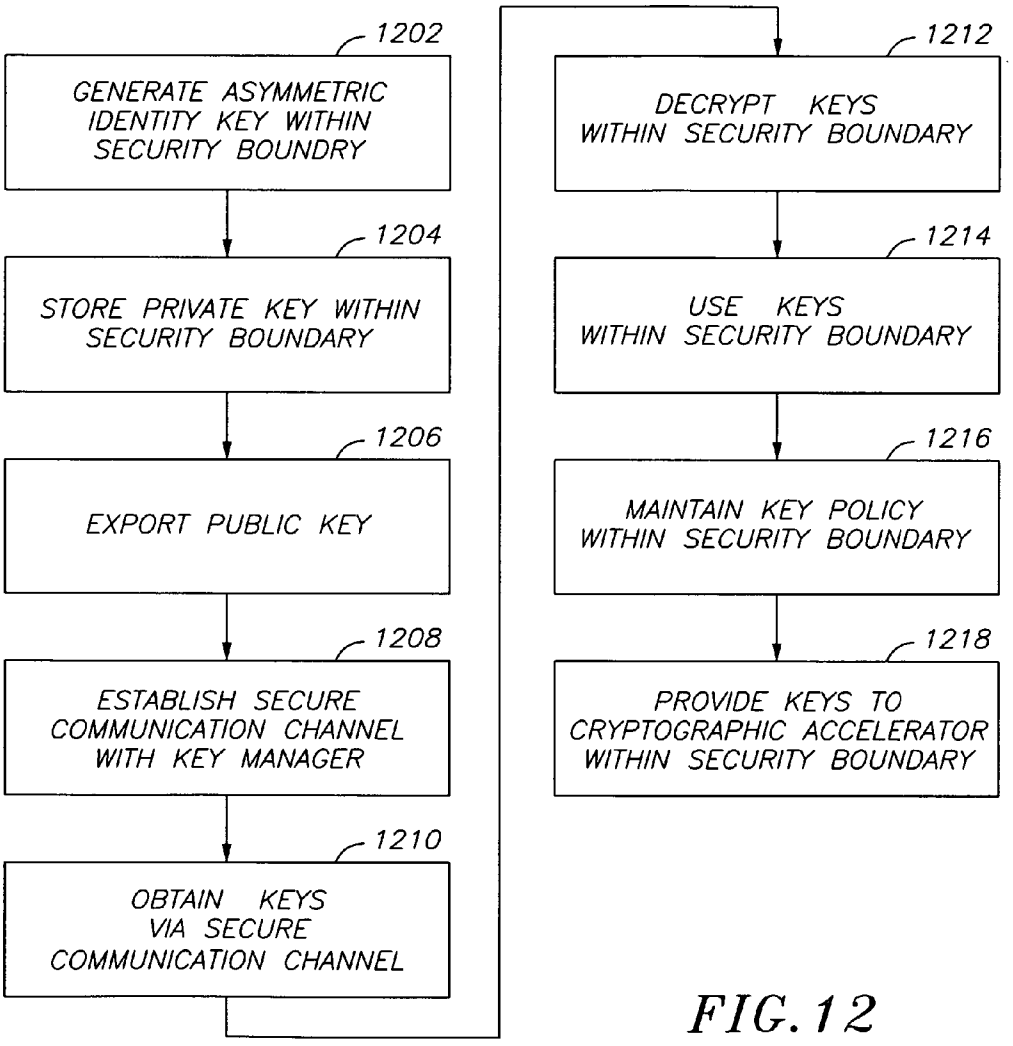
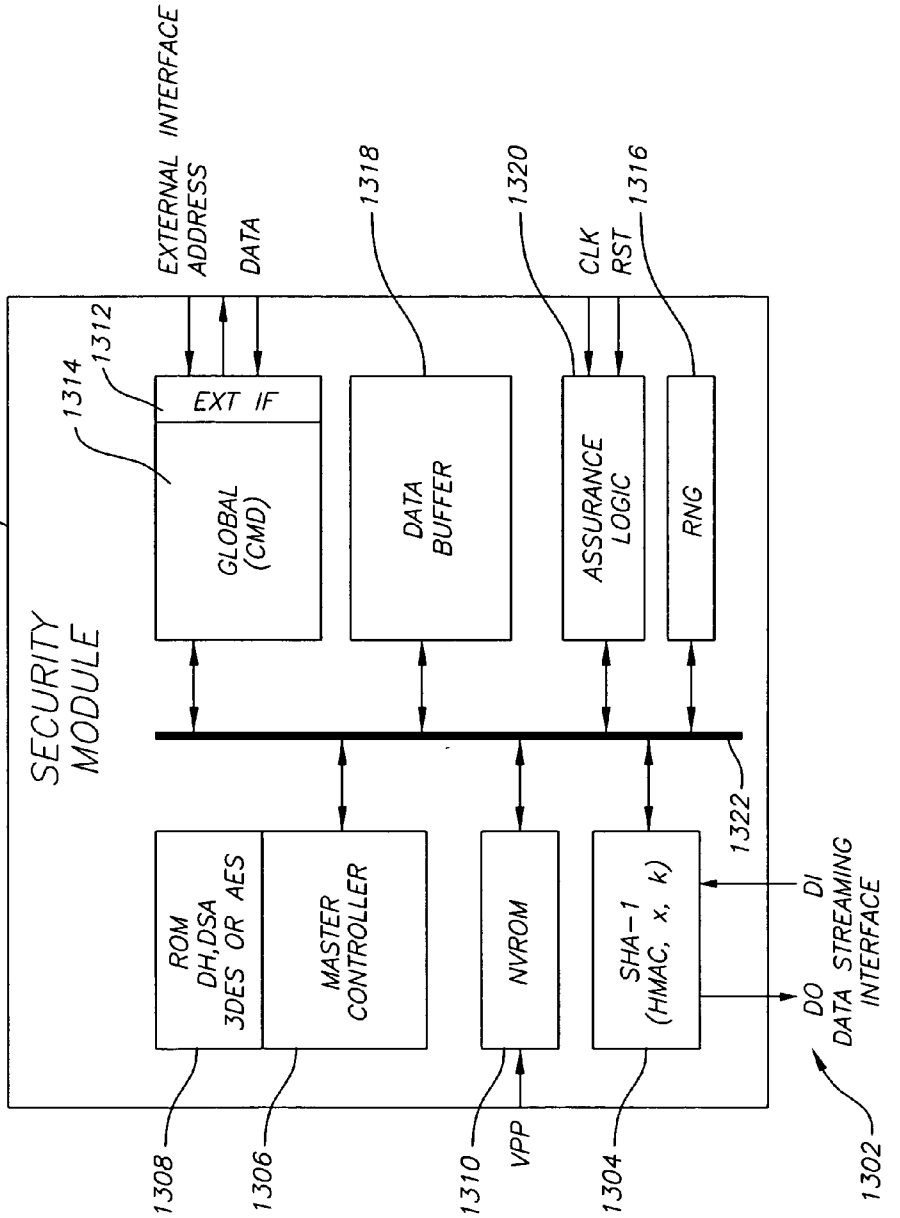

1202
GENERATE ASYMMETRIC IDENTITY KEY WITHIN SECURITY BOUNDRY
1204
STORE PRIVATE KEY WITHIN SECURITY BOUNDARY
1206
EXPORT PUBLIC KEY
1208
ESTABLISH SECURE COMMUNICATION CHANNEL WITH KEY MANAGER
1210
OBTAIN KEYS VIA SECURE COMMUNICATION CHANNEL
1212
DECRYPT KEYS WITHIN SECURITY BOUNDARY
1214
USE KEYS WITHIN SECURITY BOUNDARY
1216
MAINTAIN KEY POLICY WITHIN SECURITY BOUNDARY
1218
PROVIDE KEYS TO CRYPTOGRAPHIC ACCELERATOR WITHIN SECURITY BOUNDARY

FIG. 12

FIG. 13


EXTERNAL INTERFACE
ADDRESS
DATA
1318
1320
CLK
RST
1316
1312
1314
EXT IF
1300
SECURITY MODULE
GLOBAL (CMD)
DATA BUFFER
ASSURANCE LOGIC
RNG
1322
ROM DH,DSA 3DES OR AES
MASTER CONTROLLER
NVROM
SHA-1 (HMAC, x, k)
DI
DO
DATA STREAMING INTERFACE
1308
1306
1310
VPP
1304
1302

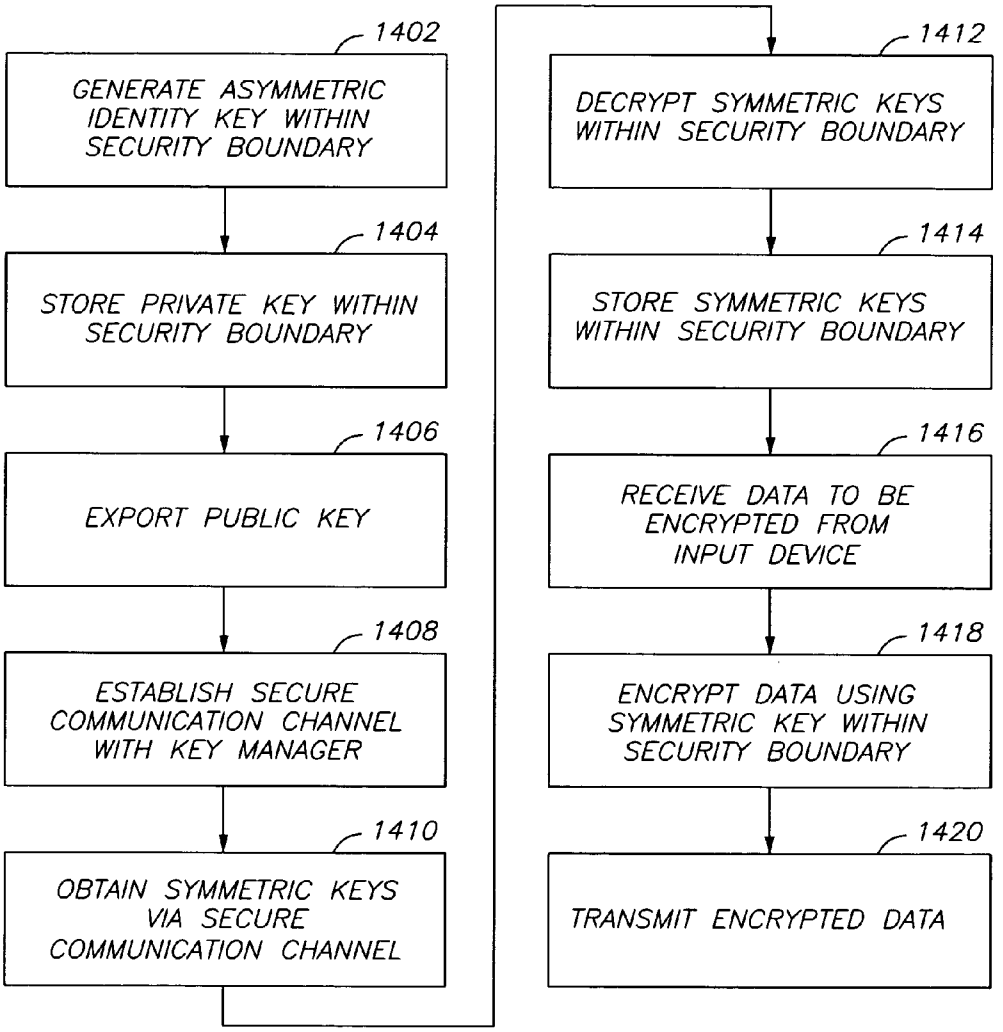

1402
GENERATE ASYMMETRIC IDENTITY KEY WITHIN SECURITY BOUNDARY
1404
STORE PRIVATE KEY WITHIN SECURITY BOUNDARY
1406
EXPORT PUBLIC KEY
1408
ESTABLISH SECURE COMMUNICATION CHANNEL WITH KEY MANAGER
1410
OBTAIN SYMMETRIC KEYS VIA SECURE COMMUNICATION CHANNEL
1412
DECRYPT SYMMETRIC KEYS WITHIN SECURITY BOUNDARY
1414
STORE SYMMETRIC KEYS WITHIN SECURITY BOUNDARY
1416
RECEIVE DATA TO BE ENCRYPTED FROM INPUT DEVICE
1418
ENCRYPT DATA USING SYMMETRIC KEY WITHIN SECURITY BOUNDARY
1420
TRANSMIT ENCRYPTED DATA

FIG. 14

SYSTEM AND METHOD FOR AUTHENTICATION VIA A PROXIMATE DEVICE

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/637,668, filed Dec. 20, 2004, the disclosure of which is hereby incorporated by reference herein.

TECHNICAL FIELD

[0002] This application relates to data processing and, more specifically, to a system and method of authenticating devices via at least one proximate device.

BACKGROUND

[0003] A variety of services may be accessed using computing devices such as personal computers and wireless handsets. For example, a user may access data stored on or applications running on the computing device. In addition, a user may connect to a data network to gain access to data and applications on remote servers.

[0004] In some cases, access to a service may be limited to authorized users. For example, a service may provide access to sensitive data such as financial information or personal information. In addition, access to a service may require payment of a fee.

[0005] A variety of techniques are known for securing access to services via a computing device. For example, a user may be required to present some form of credential to a computing device that provides the service (the "service provider"). Here, the credential may indicate that a particular user (or anyone who knows the credential) may access a given service. In some applications a credential may take the form of a user name and password that was provided to the user and the service provider by a system administrator. When the user accesses a service, the user may present the user name and password to the service provider. The service provider then verifies that this credential is assigned to an authorized user of the requested service.

[0006] In a typical data network, access to the data network is limited to devices that have been properly installed on the network. As part of this installation, cryptographic techniques may be employed to ensure that only authorized devices are connected to the network. In general, cryptographic techniques may include one or more of encryption, decryption, authentication, signing and verification.

[0007] For example, a network administrator may load one or more cryptographic keys (hereafter "key(s)") into each device that is authorized to connect to the network. The network administrator also loads corresponding keys into a network access device (e.g., a router) that is connected to, for example, a wide area network ("WAN"). When the device attempts to access the network, the network access device verifies that a proper key has been loaded into that device. Once verified, the network access device enables the requesting device access to the network.

[0008] In practice, the process of authorizing a user to use a service and installing devices on a network may be relatively cumbersome and time consuming. As described above, these operations tend to be relatively manual in nature. However, distributed computing services are becoming increasingly prevalent and affordable to access. For example, the proliferation of wireless computing networks and handheld devices enables a user to use a variety of devices to access a variety of different networks that may exist throughout a city, etc. Accordingly, a need exists for more efficient techniques for enabling a user to access secured services.

[0009] Moreover, conventional methods of entering or loading a credential or a cryptographic key into a device may be compromised in some circumstances. For example, when a user uses a computing device to access a secured service, the user may first need to enter the credential into the computing device. Typically, this is accomplished using an input device such as a keyboard. The computing device may then forward these credentials to a service provider that determines whether the user is authorized to use the requested service.

[0010] In the event the computing device has been comprised by a hacker or a computer virus, an unauthorized person may gain access to these credentials. For example, a personal computer may incorporate a trusted computing module ("TPM") to control access to certain secured services (e.g., access to an encrypted data file or a secured network). Here, the TPM may require a user to enter a password or other credential before the TPM allows the user to access these services. If the user uses a keyboard to enter this information, the password may be routed through the personal computer from the keyboard to the TPM via an insecure path. For example, the keyboard may connect to a USB port and a software driver may be used to transfer the data from the USB bus to a TPM that, for example, is connected to a South Bridge of the personal computer. However, the hacker or virus may be able to access data that is forwarded and/or stored by the software driver. As a result, an unauthorized person may acquire the password and gain access to the secured service.

[0011] Similarly, secret key information used in wireless devices may be compromised. For example, to enable secure communication between two Bluetooth devices, complementary keys may need to be loaded into each device. In some applications, a key is transferred from one Bluetooth device to the other Bluetooth device via the Bluetooth network. However, an unauthorized person may be able to intercept the broadcast Bluetooth signal containing the key. As a result an unauthorized person may acquire the key and gain access to secured services.

[0012] Serious consequences may result when the secured services control and provide access to sensitive information such as financial data or personal information. Accordingly, a need exists for more secure techniques for providing access to secured services.

SUMMARY

[0013] The invention relates to a system and method for authenticating a user or users to use one or more devices in a communication system. For convenience, an embodiment of a system constructed or a method practiced according to the invention may be referred to herein simply as an "embodiment."

[0014] In one aspect the invention relates to authenticating a user to access a service provided by or accessible via an access device (e.g., a computing device). For example, the user may access data stored on the access device or on a remote computing device. The user also may access applications running on the access device or on remote servers. In addition the user may gain access to a data network via the access device.

[0015] In one aspect of the invention, credentials for gaining access to the service are provided to an input device that is proximate the access device. Cryptographic techniques may then be used to authenticate and/or protect the credentials.

[0016] In some embodiments, a secure communication mechanism may be established between the input device and the access device for transmission of the credentials. For example, a user may initially provide the credentials to the input device in a secure manner. In some embodiments this may include entering the credentials into a security boundary in the input device. A cryptographic processing component in the input device may then cryptographically encrypt and/or sign the credentials within the security boundary. Here, the authenticity of the signing/encrypting may be verified to the access device by a published digital certificate. The input device then provides the signed/encrypted credentials to the access device.

[0017] The access device may then provide the credentials to a service provider to gain access to a service. In some embodiments, a secure communication mechanism may be established between the access device and the service provider. For example, a cryptographic processing component in the access device may cryptographically encrypt and/or sign the credentials within a security boundary. Here, the authenticity of the signing/encrypting may be verified to third parties (e.g., a service provider) by a published digital certificate. The access device then provides the signed/encrypted credentials to a service provider.

[0018] The service provider may validate that the credentials originate from a specific access device. For example, a cryptographic processor in the service provider may use the access device's public key to cause the access device to prove that it has the corresponding private key. In addition, since the service provider has access to a certificate for the public key, assurance may be provided that the access device has a mechanism for protecting keys and that the private key of the access device was not exposed outside of the security boundary. Consequently, a high level of assurance that the credentials came from a specific and/or trusted access device that is currently being used by an authorized user (as authenticated by the cryptographic processing in the input device) may be provided to the service provider.

[0019] In some embodiments authentication may be used to verify that a user is in the proximity of the access device. For example, an authorized user may be provided access to a service only when a wireless token assigned to the user is in the proximity of the input device which in turn is in relative proximity to the access device through which access to the secured service is obtained. In this way, a reasonable assumption may be made that the authorized user is in fact using a specific access device to request the service.

[0020] In some embodiments an input sensor is implemented within a security boundary on the input device. In this way, the credential may be passed via the input sensor directly to the security boundary of the input device then passed securely to the access device. As a result, the credentials may be passed to the access device without being routed via software messages or applications. As a result, the credentials may not be intercepted by a hacker or computer virus that may have compromised the software executing on the access device.

[0021] In some embodiments the input device comprises a proximity authentication system such an RFID system. For example, a user's credentials may be stored on an RFID token and the input device may include an RFID reader. In this case, the RFID reader reads the credentials when the RFID token is proximate the input device.

[0022] In some embodiments the input device may comprise a biometric sensor such as a fingerprint reader. In this case, the credentials may include biometric information (e.g., a scan of a fingerprint).

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] These and other features, aspects and advantages of the present invention will be more fully understood when considered with respect to the following detailed description, appended claims and accompanying drawings, wherein:

[0024] **FIG. 1** is a simplified block diagram of one embodiment of an authentication system constructed in accordance with the invention;

[0025] **FIG. 2** is a flow chart of one embodiment of authentication operations that may be performed in accordance with the invention;

[0026] **FIG. 3** is a simplified block diagram of one embodiment of a user authentication system constructed in accordance with the invention;

[0027] **FIG. 4** is a flow chart of one embodiment of user authentication operations that may be performed in accordance with the invention;

[0028] **FIG. 5** is a simplified block diagram of one embodiment of a user authentication system constructed in accordance with the invention;

[0029] **FIG. 6** is a flow chart of one embodiment of user authentication operations that may be performed in accordance with the invention;

[0030] **FIG. 7** is a simplified block diagram of one embodiment of a proximity-based authentication system constructed in accordance with the invention;

[0031] **FIG. 8** is a flow chart of one embodiment of proximity-based authentication operations that may be performed in accordance with the invention;

[0032] **FIG. 9** is a simplified block diagram of one embodiment of an access device constructed in accordance with the invention;

[0033] **FIG. 10** is a simplified block diagram of one embodiment of a processing system constructed in accordance with the invention;

[0034] **FIG. 11** is a simplified block diagram of one embodiment of a security module constructed in accordance with the invention;

[0035] **FIG. 12** is a flow chart of one embodiment of operations that may be performed in accordance with the invention;

[0036] **FIG. 13** is a simplified block diagram of one embodiment of a security module constructed in accordance with the invention; and

[0037] **FIG. 14** is a flow chart of one embodiment of operations that may be performed in accordance with the invention.

[0038] In accordance with common practice the various features illustrated in the drawings may not be drawn to scale. Accordingly, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. In addition, some of the drawings may be simplified for clarity. Thus, the drawings may not depict all of the components of a given apparatus or method. Finally, like reference numerals denote like features throughout the specification and figures.

DETAILED DESCRIPTION

[0039] The invention is described below, with reference to detailed illustrative embodiments. It will be apparent that the invention may be embodied in a wide variety of forms, some of which may be quite different from those of the disclosed embodiments. Consequently, the specific structural and functional details disclosed herein are merely representative and do not limit the scope of the invention.

[0040] In one aspect, the invention relates to systems and methods that provide device and/or user level authentication. For example, various techniques are described for authenticating that a user is using a device. In addition, various techniques are described for authenticating a device to a service such as enabling access to a data network.

[0041] In a conventional data network device level authentication may be used to ensure that only authorized devices are allowed to connect to the network. Here, cryptographic techniques may be employed to authenticate that a device that is attempting to connect to the network is the device it purports to be and is authorized to use the network. For example, a device typically connects to the network via an access point such as a router. Compatible cryptographic keys are thus provided to the router and to authorized devices to enable these devices to perform cryptographic operations that provide the desired authentication. In such a network, a mechanism must be provided for securely distributing keys to all devices that may connect to the network. Traditionally, this has been accomplished by the user or a network administrator manually loading the keys into the devices (e.g., via a keyboard or a software program).

[0042] Such device level authentication may have a number of drawbacks. For example, there may not be any verification as to which user is using the device. Moreover, when multiple users use the same device, there may not be an efficient mechanism to determine which verification information (e.g., cryptographic certificate) should be used to authenticate to the system.

[0043] **FIG. 1** illustrates one embodiment of a system **100** constructed in accordance with the invention where one or more users (not shown) may use one or more access devices **102** and **104** to access services (e.g., connect to a data network) via an access server **106**. For example, to access a service a user presents authentication information (e.g., credentials such as a password) to an input device **108**. For convenience the term "credential(s)" may be used to refer generally to any type of information that a user may present for authentication purposes.

[0044] The input device **108** may include a security processing component (e.g., a security module **110**, a processor with code for cryptographic operations, etc.) that provides cryptographic processing and may incorporate other security mechanisms. For example, the security module **110** may include one or more cryptographic processors that perform cryptographic operations such as encryption, decryption, authentication, verification and signing. Using the security module **110**, the input device **108** may authenticate the credentials received from the user. The input device **108** may then securely send the credentials via an interface (e.g., an RF interface **124**) to an access device **102** or **104** via signals **118** through a medium (e.g., a wireless medium).

[0045] The access device **102** or **104** includes an interface (e.g., RF interface **126** or **128**) for receiving the signals **118**. The access device **102** or **104** includes some form of processing (e.g., access processor **130** or **132**) for accessing a service. For example, in some embodiments the access processor may comprise a processor for a cell phone or some other form of wireless device.

[0046] The access device **102** or **104** also may include a security processing component (e.g., security module **112** or **114**) that provides cryptographic processing and may incorporate other security mechanisms. For example, a security module may include one or more cryptographic processors that perform cryptographic operations such as encryption, decryption, authentication, verification and signing. Using the security module, an access device **102** or **104** may authenticate the credentials received from the input device **108**. The access device may then securely send the credentials via an interface (e.g., interface **134** or **136**) to the access server **106** via signals **120** over a medium (e.g., a wireless medium).

[0047] The access server **106** includes an interface (e.g., interface **138**) for receiving the signals **120**. The access server includes some form of processing **140** for providing access to a service. For example, in some embodiments the access processor may comprise a network server for a wired and/or wireless network.

[0048] The access server **106** also may include a security processing component (e.g., security module **116**, a key manager, etc.) that provides cryptographic processing and may incorporate other security mechanisms. Here, the security module **116** may process the received credentials to, for example, authenticate and/or decrypt the credentials. The above architecture may thus provide relatively strong authentication to the access server **106** that the credentials have been presented to a trusted input device **108** that is associated with a trusted access device **102** or **104**. As a result, the access server **106** may enable the access device **102** or **104** to access the requested service.

[0049] Selected operations of the system **100** will be explained in more detail in conjunction with the flowchart of **FIG. 2**. As represented by block **202**, one or more keys may be generated to enable the input device **108** to securely

communicate with an access device (e.g., access device **102**). In some embodiments, this is accomplished through the use of asymmetric keys.

[**0050**] For example, a unique asymmetric identity key may be provided for the input device **108** during manufacture or at some later time. The private key portion of this asymmetric key may be stored within a security boundary (e.g., the security module **110**) in the input device **108**. For example, a processor (e.g., a multi-purpose processor or a cryptographic processor) may generate the key within this security boundary and the private portion of the key may never be allowed to appear outside of the security boundary in the clear (i.e., unencrypted). Additional details of a security boundary are provided below.

[**0051**] The public portion of the key may then be published with a digital certificate. For example, the manufacturer of the input device may publish the public key and the certificate on a publicly accessible server. The certificate may serve to verify that the public key is authentic, that the private key has not been disclosed outside the security boundary and that the input device that holds the private key provides a mechanism to securely receive, use and maintain keys. Thus, the certificate serves to strongly verify the authenticity of any information provided by an input device that has the corresponding private key.

[**0052**] In some embodiments, the input device and the access device may use the asymmetric key to negotiate one or more other keys that may be used for cryptographic processing. For example, these other keys may be used to encrypt, decrypt, sign, etc., information send between these components. In this way, an authenticated and/or secure channel may be established between the input device and the access device. That is, each component will have one or more keys that enable it to encrypt, decrypt or authenticate information that it sends to or receives from the other component. In this way, sensitive information (e.g., credentials or keys) may be securely sent over a link **118** (e.g., a wireless link such as Bluetooth, etc.) that may not otherwise be secure.

[**0053**] Referring now to block **204**, keys also may be generated for the security module in the access device during manufacture or at some later time. Thus, a unique asymmetric identity key may be provided for the access device **102**. The private key portion of this asymmetric key may be stored within a security boundary (e.g., the security module **112**) in the access device **102**. The public portion of the key may then be published with a digital certificate that may serve to verify that the public key is authentic, that the private key has not been disclosed outside the security boundary and that the access device that holds the private key provides a mechanism to securely receive, use and maintain keys. Thus, the certificate serves to strongly verify the trustworthiness of the access device. This asymmetric key pair may then be used to establish an authenticated and/or secure channel between the access device and the access server or some other device.

[**0054**] Referring now to block **206**, once the devices are installed in the field, the devices and the access server may establish secure channels over media that may otherwise be insecure. In some embodiments this may involve performing asymmetric key exchange operations.

[**0055**] At block **208**, to enable the access server to recognize the credentials assigned to a given user, the credentials are enrolled (e.g., entered into) the access server. This may be accomplished, for example, using a credential enrollment mechanism. Additional details of various credential enrollment mechanisms are discussed below.

[**0056**] The credential enrollment mechanism provides the credential information to the security module **116** which may then generate one or more keys associated with that credential. These keys may comprise, for example, SSL or IPsec keys/security associations that may enable the user to log onto a security network.

[**0057**] Referring to block **210**, when a user wishes to access a service via the access device **102**, the user presents his or her credentials to a data input component **122** on the input device **108**. The data input component may comprise a keypad, an RFID reader, a sensor, etc.

[**0058**] In some embodiments the input device **108** is a biometric sensor. For example, the sensor may comprise a fingerprint reader. Alternatively, the sensor may comprise a retina/iris scanner, an audio input device (e.g., a microphone) for speech recognition, a camera sensor (e.g., a CCD device) for, e.g., facial feature recognition or a DNA typing device. In addition, appropriate processing may be provided on the sensor integrated circuit to facilitate retrieval and analysis of this information.

[**0059**] In some embodiments credentials may be provided to the input device via a direct path into the security boundary of the input device. For example, credentials may be directly entered into a device located within a security boundary. This may be accomplished, for example, using a keyboard, an RFID reader, a biometric sensor, etc., that is physically attached to a component within the security boundary. Additional details of these types of components are discussed below.

[**0060**] Referring to block **212**, the input device **108** sends the credentials to the access device **102** via the authenticated and/or secure channel discussed above. For example, a cryptographic processor in the input device may use a key obtained from the negotiation with the access device **102** discussed above to sign and/or encrypt the credentials. Typically, the cryptographic processor signs the credentials using such a key or the private key of the input device.

[**0061**] Referring to block **214**, the access device **102** processes the credentials, as necessary, and sends the credentials to the access server **106** via the authenticated and/or secure channel **120** discussed above. For example, a cryptographic processor in the access device **102** may use a key obtained from the negotiation with the access server **106** discussed above to encrypt the credentials. Typically, the cryptographic processor signs the credentials using such a key or the private key of the access device **102**.

[**0062**] At block **216**, cryptographic processor(s) in the access server **106** process the encrypted/signed credentials. Through this cryptographic process, the access server obtains strong authentication that the credentials are from a user that is using a specific access device **102**. Moreover, assurances may be made via the certificate that the input device (e.g., keyboard, sensor, RFID components, etc.) through which a user inputs credentials is proximate to that access device.

[**0063**] The access server **106** then checks the credential database to verify that the credentials are associated with an

authorized user. If so, the access server **106** generates or retrieves the key (e.g., key A) that corresponds to that credential or otherwise enables access to a requested service. The access server may then, for example, send the key to the access device **102** (block **218**). Typically, the cryptographic processor **124** will encrypt the key to protect it during transmission. Here, the cryptographic processor may use a negotiated key or the public key associated with the private key to encrypt key A.

[**0064**] Once the access device **102** receives encrypted key A, the cryptographic processor decrypts key A and uses it to, for example, establish a connection with a network (block **220**).

[**0065**] Referring now to **FIG. 3** additional details of the authentication process will be discussed. **FIG. 3** illustrates one embodiment of a system **300** constructed in accordance with the invention where one or more users (not shown) may use one or more access devices **302** and **304** to access services **330** (e.g., connect to a data network) via an access server **306**. For example, to access a service a user presents authentication information (e.g., credentials **308** such as a password) to the access device **302** via a proximate input device (not shown). For convenience the term "credential(s)" may be used to refer generally to any type of information that a user may present for authentication purposes.

[**0066**] The access device **302** may include a security module that provides cryptographic processing and may incorporate other security mechanisms. For example, a security module may include one or more cryptographic processors **328** that perform cryptographic operations such as encryption, decryption, authentication, verification and signing. Using the security module, the access device **302** may authenticate the credentials received from the input device and securely send the credentials to a key manager **310** in the access server **306**.

[**0067**] The key manager **310** provides a secure environment for generating, assigning and maintaining keys that are used in the system. The key manager includes one or more cryptographic processors **324** for securely performing cryptographic operations including encryption, decryption, authentication, etc. The key manager also includes a secure data memory **322** for storing keys **326** in a manner that prevents the keys from being accessed by unauthorized persons or methods.

[**0068**] To provide secure processing and key storage a security boundary is associated with and enforced by the key manager. This security boundary may be established, for example, using hardware and/or cryptographic techniques.

[**0069**] Hardware techniques for providing a security boundary may include, for example, placing components within a single integrated circuit. In addition, one or more integrated circuits may be protected by a physical structure using tamper evident and/or tamper resistant techniques such as epoxy encapsulation.

[**0070**] Encryption techniques for establishing a security boundary may include, for example, encrypting any sensitive information before it leaves the key manager. For this purpose, the key manager may use one or more of the cryptographic processors **324** and store the associated encryption/decryption keys **326** in an internal secure data memory **322**.

[**0071**] To maintain the security of the system **300**, any keys distributed by the key manager to other components in the system should be adequately protected. For example, provisions may be made to ensure that keys are only delivered to authorized devices. In addition, provisions may be made to protect the keys during distribution and within the recipient devices.

[**0072**] In some embodiments the access device **302** includes one or more cryptographic processors **328** and keys (e.g., key **314**) to authenticate information that is sent from the access device **302** to the access server **306**, to facilitate secure transmission of keys to the access device **302**, and to protect the keys used by the access device **302**.

[**0073**] For example, using digital certificates and other cryptographic processes the access device **302** may provide strong authentication to the access server **306** that the credentials it sends to the access server **306** are from a user that is using that specific access device. In addition, these processes may be used to verify that the access device **302** provides a high level of protection for key material.

[**0074**] Once this authentication is provided to the access server **306**, the key manager **310** may safely distribute keys to the access device **302** to facilitate access to the desired service. For example, the key manager may distribute keys to the access device to enable the access device to connect to a data network.

[**0075**] The embodiment of **FIG. 3** provides an efficient mechanism that enables a user to, for example, use a variety of access devices to gain access to a network. Here, the user initially authenticates himself or herself to each device. The access server then automatically builds the network by distributing the necessary keys to each device. As described herein this process may be accomplished with a high level of security. Moreover, since the access server provides the appropriate keys to each device, the key material does not need to be given to the user. In addition, the user may not be required to, for example, provide a digital certificate to each access device he or she uses in the network.

[**0076**] Selected operations of the system **300** will be explained in more detail in conjunction with the flowchart of **FIG. 4**. As represented by block **402**, one or more keys may be generated to enable the access device to securely communicate with the access server. In some embodiments, this is accomplished through the use of asymmetric keys.

[**0077**] For example, a unique asymmetric identity key **314** may be provided for each access device. The private key portion of this asymmetric key may be stored within a security boundary (represented by dashed line **312**) in the access device. For example, a cryptographic processor **328** may generate the key within this security boundary and the private portion of the key may never be allowed to appear outside of the security boundary **312** in the clear (i.e., unencrypted). Additional details of a security boundary are provided below.

[**0078**] The public portion of the key may then be published with a digital certificate. For example, the manufacturer of the access device may publish the public key and the certificate on a publicly accessible server. The certificate serves to verify that the public key is authentic, that the private key has not been disclosed outside the security boundary and that the access device that holds the private

key provides a mechanism to securely receive, use and maintain keys. Thus, the certificate serves to strongly verify the authenticity of any information provided by an access device that has the corresponding private key.

[0079] In some embodiments, the access device and the access server may use the asymmetric key to negotiate one or more other keys that may be used for cryptographic processing. For example, these other keys may be used to encrypt, decrypt, sign, etc., information send between these components. In this way, a secure channel (represented by dashed lines **316**) may be established between the access device and the access server. That is, each component will have one or more keys that enable it to decrypt encrypted information that it received from the other component. In this way, sensitive information (e.g., keys) may be securely sent over a link **318** that may not otherwise be secure.

[0080] Referring now to block **404**, to enable the access server to recognize the credentials assigned to a given user, the credentials are enrolled (e.g., entered into) the access server. This may be accomplished, for example, using a credential enrollment mechanism **320**. In some embodiments the credential enrollment mechanism may comprise a keyboard and monitor console for the server. In some embodiments the credential enrollment mechanism **320** may be inside a security boundary associated with and enforced by the key manager **310**. For example, the credential enrollment mechanism **320** may comprise a keyboard that is physically attached to the key manager, an RFID reader, a biometric sensor, etc. Additional details of these types of components are discussed below.

[0081] The credential enrollment mechanism **320** provides the credential information to the key manager **310** which may then generate one or more keys associated with that credential. These keys may comprise, for example, SSL or IPsec keys/security associations that may enable the user to log onto a security network. The key manager may then maintain a database that associates each authorized user's credential (e.g., credential A) with key(s) and certificate(s) (e.g., key A) that may be generated for that user.

[0082] The credentials and the associated key(s) may be stored in a secure data memory **322**. In some embodiments the data memory **322** may be protected within a physical security boundary of the key manager **310**. For example, the database **322** may be located within a secure enclosure and/or within the same integrated circuit as the key manager. In some embodiments the data memory **322** may be located external to the key manager. In this case, however, the key manager may encrypt the keys before they are stored in the data memory.

[0083] Referring to block **406**, when a user wishes to access a service via the access device **302**, the user presents his or her credentials **308** to the access device. As discussed above, the credentials **308** are provided to the access device via a proximate input device.

[0084] In some embodiments credentials may be provided from the input device to the access device via a direct path into the security boundary of the access device. For example, in the access device **304** credentials **332** may be directly entered (as represented by dashed line **334**) into a device located within a security boundary **336**. This may be accomplished, for example, using a wireless interface that is physically attached to a component within the security boundary.

[0085] Referring to block **408**, the access device **302** sends the credentials **308** to the access server **306** via the secure channel **316** discussed above. For example, a cryptographic processor **328** may use a key obtained from the negotiation with the access server **306** discussed above to encrypt the credentials. Typically, the cryptographic processor(s) **328** sign the credentials using such a key or the private key **314**.

[0086] At block **410**, cryptographic processor(s) **324** in the access server **306** process the encrypted/signed credentials. Through this cryptographic process, the access server obtains strong authentication that the credentials are from a user that is using a specific access device **302**. Moreover, assurances may be made via the certificate that an input device (e.g., keyboard, sensor, RFID components, etc.) through which a user inputs credentials is proximate to that access device.

[0087] The access server **306** then checks the credential database to verify that the credentials are associated with an authorized user. For example, the access server may determine whether the credential matches a credential (e.g., credential A) stored in the data memory **322**.

[0088] If so, the access server **306** generates or retrieves the key (e.g., key A) that corresponds to that credential. The access server then sends the key to the access device **302** (block **412**). Typically, the cryptographic processor **324** will encrypt the key to protect it during transmission. Here, the cryptographic processor may use a negotiated key or the public key associated with the private key **314** to encrypt key A.

[0089] Once the access device **302** receives encrypted key A, the cryptographic processor **328** decrypts the key and stores decrypted key A **340** within the security boundary **312**. Here, the cryptographic processor **328** may use a negotiated key or the private key **314** to decrypt key A. The access device **302** may then use key A **340** to, for example, establish a connection with a network (block **414**).

[0090] If desired, the user may then use another access device (e.g., access device **304**) to access the network. Again, the user presents his or her credentials (e.g., the same credentials referred to above) to access device **3.04** via the input device (not shown). Cryptographic processor(s) **342** may then encrypt/sign the credentials and send them to the access server via a secure channel **346** over a link **348** that may not otherwise be secure. Again, an asymmetric identity key **344** may be used to establish the secure channel **346**, form the basis of a digital certificate, sign credentials, etc. The access server **306** then verifies the credentials. Here, since the access server has received the same credentials it may assume that the same user has authenticated to the access device **304**. Accordingly, the access server sends the same key (e.g., key A) to the access device **304** via the secure channel **346**, thereby binding these access devices together. The cryptographic processor **342** decrypts encrypted key A and stores decrypted key A **350** within the security boundary. Access device **304** may then use key A to connect to a network or access another service.

[0091] In addition, more than one set of credentials may be presented to a given access device to access a network. For example, multiple users that are assigned different credentials may share an access device. In addition, the same user may have different credentials that provide access to differ-

ent services such as personal services or employer provided services. Accordingly, another set of credentials may be stored in the access server database and associated with a unique key (e.g., key B). When these other credentials are presented to the access device **304**, the key B will be provided to the access device **304** using the secure techniques discussed above. Accordingly, access device may use the key B **350** to establish a separate, cryptographically secure connection to a network.

[**0092**] These aspects of the invention will be described in more detail in conjunction with **FIGS. 5 and 6**. **FIG. 5** is a simplified diagram of one embodiment of a network system that may support a variety of communication and data processing devices.

[**0093**] In **FIG. 5** access devices connect to a wide area network ("WAN") **502** such as the Internet via an access point (e.g., a router) **504**. Here, the access point may serve as the access server discussed herein. Alternatively, the access point **504** may connect to an access server (not shown) such that the credentials and keys pass through the access point as they are sent between the access server and the access devices. In either case, credentials for any users that are authorized to access the system may be enrolled with the access server.

[**0094**] The access point **504** may provide connectivity for wired or wireless devices. For example, a network printer **512** may be connected to the access point by a wired connection as represented by line **506**. A voice-over-Internet-Protocol ("VoIP") phone **514** also may connect to the access point via a wired connection as represented by line **508**.

[**0095**] Other devices may connect to the access point via radio frequency ("RF") signals as represented, for example, by the curved lines **510**. Here, the access point **504** may support wireless standards such as Bluetooth, 802.11, GSM, etc.

[**0096**] Examples of access devices include a VoIP phone **514** that supports the Bluetooth protocol; a laptop computer **516** that supports 802.11 and/or Bluetooth; a personal digital assistant ("PDA") **518** that supports 802.11 and/or Bluetooth and may include a cellular telephone that supports, for example GSM; a personal entertainment device **520**; a phone **522** that supports GSM and/or 802.11 and that communicates with peripherals such as a wireless headset **524** via Bluetooth; and a personal computer **526** that supports an 802.11 wireless connection and that communicates with wireless peripherals such as a Bluetooth-enabled keyboard **528** and mouse **530**.

[**0097**] As discussed herein, each of the devices **512-530** may include a security module (not shown) that enables the device to securely and efficiently receive any keys necessary to connect to the data network **502** and/or to other devices. In the latter case, for example, keys may be securely distributed between devices to enable a peripheral (e.g., keyboard **528**) to securely communicate with a base device (e.g., computer **526**). Accordingly, users may connect any of these devices to the network or other devices by simply providing their credentials to one or more input devices **536** which then route the credentials to the device(s) as discussed herein. For example, an input device **536** may communicate with a device **512-530** to provide a credential to a device **512-530**. In the case of the peripherals (e.g., keyboard **528**), the credentials may be passed through the base device (e.g., computer **526**), then routed to the access server **504**.

[**0098**] Additional details of the authentication components and processes that may be incorporated into these devices are described herein. For example, several embodiments for providing credentials to an access device or an access server are discussed below in conjunction with **FIGS. 7-10**. In addition, several embodiments of security modules are discussed below in conjunction with **FIGS. 11-14**.

[**0099**] Referring to **FIG. 6**, a simplified flowchart is illustrated relating to operations that may be performed in a network system (e.g., as shown in **FIG. 5**). For example, such a system may include multiple access devices and support multiple users and multiple levels of credentials. In general, these operations may be performed as discussed herein, for example, in conjunction with **FIGS. 3 and 4**. For convenience, not all of the operations involved in the process are illustrated in **FIG. 6** or discussed below.

[**0100**] As represented by block **602**, a credential for a user (referred to for convenience as "user A") is enrolled with the access server. At block **604**, user A presents his or her credential to an input device that then sends the credential to an access device (referred to for convenience as "access device **1**"). The access device **1** sends the credential to the access server and, after the access server verifies that the credential has been enrolled, the access server sends the associated key(s) to the access device **1** (block **606**). Access device **1** may then use the key(s) associated with user A to connect to the network (block **608**).

[**0101**] Blocks **610-614** illustrate that a network may be automatically built as a user provides his or her credentials to multiple access devices in the system. As represented by block **610**, user A may provide his or her credential to another access device (referred to for convenience as "access device **2**") via the input device. The access device **2** sends the credential to the access server and, after the access server verifies that the credential has been enrolled, the access server sends the associated key(s) to the access device **2** (block **612**). Access device **2** may then use the key(s) associated with user A to connect to the network (block **614**).

[**0102**] Blocks **616-622** illustrate that a given device may be used by several users to access the network. Here, each of the users may be assigned different credentials. As represented by block **616**, a credential for another user (referred to for convenience as "user B") may be enrolled with the access server. At block **618**, user B also may provide his or her credential to the access device **1** via the input device. The access device **1** sends the credential to the access server and, after the access server verifies that the credential has been enrolled, the access server sends the associated key(s) to the access device **1** (block **620**). Access device **1** may then use the key(s) associated with user B to establish an entirely separate and cryptographically secure connection with the network (block **622**).

[**0103**] In practice, the separate set of credentials identified above as being associated with user B may be a second set of credentials assigned to a given user (e.g., user A). For example, a user may have one set of credentials assigned for one network (e.g., a home network) and another set of

credentials assigned for access to another network. Referring to **FIG. 5**, the devices **514** and **516** may be used to connect to an enterprise LAN at the user's office. In this case, the second set of credentials may be provided to the office network **534** via the WAN **502** and other routing mechanisms **532**. Once the appropriate keys are exchanged, an enterprise virtual private network ("VPN") or other form of connection may be established between the access device and the office network **534**. Again, this network may be entirely separate and cryptographically secured from any other network connections for that user or any other user of the system.

[**0104**] Blocks **624-628** illustrate that the network may be continued to be automatically built as other users provide his or her credentials to multiple access devices in the system. As represented by block **624**, user B may provide his or her credential to another access device (referred to for convenience as "access device **3**"). The access device **3** sends the credential to the access server and, after the access server verifies that the credential has been enrolled, the access server sends associated key(s) to the access device **3** (block **626**). Access device **3** may then use the key(s) associated with user B to connect to the network (block **628**).

[**0105**] The system described above may provide several advantages as compared to conventional systems. Traditional networks may only provide device level authentication that is achieved by manually configuring the head end and all devices that may connect to the network. For example, the router may be configured by an administrator physically connected to a LAN port of the router. Here, the administrator may enter in the keys for the router and identify each of the devices that may connect to the router. In addition, the administrator may manually configure each device in the network with the necessary key to enable the device to connect to that specific router.

[**0106**] In contrast, a network constructed using the teachings described herein may be automatically built by binding components (e.g., access devices) together as a user authenticates himself or herself to these components. This is facilitated, for example, by the ability to securely authenticate at the system level. For example, the proximity of the user may be verified as well as the ability of a security module to protect keys (e.g., using appropriate hardware).

[**0107**] A variety of secure techniques may be used to authenticate a user to a device. For example, a credential may be provided via a direct connection into an input device, credentials may be injected into a security boundary of a device via RFID signals or a sensor may be physically located within a security boundary of a device.

[**0108**] Here, the network may be built using digital certificates based on public/private keys pairs. This process may be initiated by using a private key that is protected on each component and may provide a secure environment where the components may dynamically change the keys.

[**0109**] In addition, each user does not need access to the keys that identify that user since the user does not need to pre-configure each device with the appropriate key. Instead the user may only present information such as a credential to obtain access to the network via a given device.

[**0110**] Moreover, a system may be configured to provide multiple networks. Each of these networks may include a given set of components that are defined for different users and/or for different permission levels for a given user. These networks may be secured from one another by using cryptographic techniques to authenticate access to each network and secure the data flowing though each network.

[**0111**] Referring now to **FIGS. 7-10**, several embodiments of mechanisms for providing credentials to a device will be discussed. In general, the following description describes providing credentials to an access device. However, these mechanisms also may be used to provide credentials to an access server or some other component in a system.

[**0112**] **FIG. 7** illustrates one embodiment of a system **700** where selected services may be provided to a user via a computing device when a wireless token assigned to a user is proximate to the input device. An input device **716** includes components that may be used to determine whether a wireless token (e.g., an RFID token) **742** assigned to a user or users is proximate to the input device **716**. For example, a wireless proximity reader (e.g., an RFID reader **728**) may be configured to receive signals **744** (e.g., RF signals) from the wireless proximity token **742**. The signals **744** may include information that uniquely identifies the wireless proximity token **742**. For example, this information may include one or more credentials (e.g., a password) that may be used to access a secured service through an access server **704**.

[**0113**] The determination of proximity between the token **742** and the reader **728** may be established using a variety of mechanisms depending on the application. In some embodiments, the token will not generate signals until it is within a given distance of the reader. This may be accomplished, for example, by using a relatively passive token that intercepts signals transmitted by the reader and transmits signals in response to the received signals. Different distances between the token **742** and the reader **728** may be defined as indicative of proximity depending on the requirements of the application and, in some cases, characteristics of the operating environment.

[**0114**] RF interfaces (e.g., Bluetooth interfaces) **736** and **706** and associated antennas **734** and **732** may then be used to send the credentials from the input device **716** to the access device **702** via RF signals **730**. The RF interfaces also may be used for other communications between the input device **716** and the access device **702**.

[**0115**] An access device **702** such as a computer may request access to a service from the access server **704** by sending a request over a communication link **726**. Depending upon the particular application, the communication link **726** may comprise, for example, electric wires, optical cables or air. Thus, the access device **702** may support wired or wireless communications with the access server **704**.

[**0116**] Typically, access to the service will be initiated by the user's interaction with the access device **702**. For example, the user may use a keyboard or pointing device (e.g., a computer mouse) to access the service. In conjunction with this the user may be required to input a password and/or provide a biometric (e.g., a fingerprint) to a biometric sensor to verify the authenticity of the user. In this way, access to a service may be withheld until the user provides adequate credentials including, for example, what the user knows (e.g., a password), what the user possesses (e.g., a token) and who the user is (e.g., a physical or biometric characteristic).

[0117] The input device **716** and the access device **702** may incorporate security mechanisms to ensure that the credentials provided by a user may be secured when the credentials are maintained within and sent from these devices. For example, the input device may provide a security boundary within which any sensitive information (e.g., credentials received from the token and keys received from the access device) may be used and maintained in a secure manner. In addition, the access device may provide a security boundary to protect any sensitive information (e.g., keys and credentials)

[0118] To this end, these devices may include security modules **708** and **746** that provide cryptographic processing to, for example, sign and/or encrypt the credentials. In some embodiments information may only pass between the reader **728** and the security module **746** via a connection within a common integrated circuit. Thus, the input device may be configured so that the credentials never leave the integrated circuit in the clear.

[0119] In addition, the access device **702** may be in secure communication with the access server **704**. For example, a cryptographically secured communication channel **718** may be established between the security module **708** and the access server **704**. In this case, the security module **708** may process (e.g., encrypt/sign) the credentials before sending them to the access server **704**. Accordingly, the security modules may provide strong authentication that the credentials are from a specific token **742** that is proximate that particular input device **716** that, in turn, is relatively proximate a specific access device **702**.

[0120] After the access server **704** has received authenticated credentials from the access device **702**, the access server may provide access to the requested service. As used herein the term service may include, for example, access to data and/or a data processing service. Thus, a service may enable an access device to, for example, read or write data in a data memory, access encrypted data, use cryptographic keys, gain access to cryptographic material such as security associations and keys, access a web page, access a data network or access a processing application.

[0121] As used herein the term data may include any information that may be accessed by a computing device including, for example, data files, passwords and cryptographic security associations including keys.

[0122] As used herein the term access may include, for example, acquiring, using, invoking, etc. Thus, data may be accessed by providing a copy of the data to the access device. Data also may be accessed by enabling the access device to manipulate or use the data. As an example of the latter, once a user has been authorized to access a service a trusted platform module may use keys to perform operations for the user. For a data network, access may include, for example, sending and/or receiving data over the network. For a processing application access may include, for example, invoking, interacting with or using the application or loading the application onto the access device.

[0123] An access server may comprise hardware and/or software that facilitate providing a service. For example, an access server may consist of a processing system that processes requests for service, verifies whether the requester is authorized to access the service and provides or facilitates the requested access.

[0124] In practice, an access server may be located local or remote with respect to the entity requesting service (e.g., access device **702**). For example, a local trusted platform module may control access to passwords in a computing system. In addition, a remote wireless access point may control a computing system's access to a data network connected to the access point.

[0125] An access device may comprise hardware and/or software that facilitate access to a service. For example, an access device may comprise a computing system such as, without limitation, a personal computer, a server, a cellular phone, a personal data assistant ("PDA"), etc.

[0126] For convenience, **FIG. 7** only depicts one token, input device, access device and access server. It should be understood, however, that a system may include any number of these components. For example, a user may use a token to access one or more services via one or more access devices. Thus, an access device may access services from multiple access servers. Also, multiple access devices may access the services provided by a given access server.

[0127] Authorization to access a service may depend on the specific token and access device being used. For example, a user may be assigned one token to access certain services through certain access devices. In addition, the user may be assigned another token to access other services through the same or other access devices. Also, multiple sets of information (e.g., credentials) may be included on a single token to enable a user to access different services or to enable multiple users to share a token.

[0128] A wireless proximity reader and token may be implemented using one or more of a wide variety of wireless proximity techniques. For example, the proximity reader and the token may support, without limitation, one or more of RFID, ISO 14443 and ISO 15693.

[0129] Tokens may be implemented in various physical forms depending upon the needs of the respective applications. For example, a token may be in a form that is easy to carry, similar to a plastic credit card, a "smart card" or a building access card. Also, a token may take the form of a tag or a label that may be attached to another article.

[0130] Examples of tokens may include, without limitation, smart cards, credit cards, dongles, badges, biometric devices such as fingerprint readers, mobile devices such as cellular telephones, PDAs, etc. In some embodiments, the token includes circuitry used in a typical smart card. For example, the token may store an encrypted password that may be sent to an authentication system.

[0131] Referring now to **FIG. 8** additional details of operations and configurations in a proximity-based authentication system will be described. As represented by block **802**, a security boundary is provided within the input device **716** and the access device **702** to, for example, secure the process of gaining access to a service, including securing the authentication process and information used during the authentication process. This security boundary may be established, for example, using hardware and/or cryptographic techniques.

[0132] Hardware techniques for providing a security boundary may include, for example, placing components within a single integrated circuit. As shown in **FIG. 7** an RF

interface **706**, a security module **708** and other processing components **710** may be incorporated into a single integrated circuit **712**. Thus, any processes performed or information used or stored within the integrated circuit **712** may not be compromised absent physical access to the integrated circuit **712** and the use of an invasive technique for analyzing the internal operations and data of the integrated circuit **712**. For many applications, this form of hardware security boundary may provide an acceptably high level of security.

[**0133**] Other means may be used to provide a security boundary. For example, one or more integrated circuits (e.g., integrated circuit **712**) may be protected by a physical structure using known techniques (e.g., epoxy encapsulation). Also, the access device **702** and/or its internal components may be tamper resistant and/or tamper evident.

[**0134**] Cryptographic techniques for providing a security boundary may include encrypting any important information that is sent to or from the integrated circuit via non-secure paths in the system. For example, security associations and keys may only appear in the clear within the integrated circuit **712**. In the event keys need to be sent out of the integrated circuit **712** (e.g., to be stored in a data memory **714**), the keys may first be encrypted.

[**0135**] Similarly, any important information that is sent between the integrated circuit **712** and the access server **704** may be encrypted. For example, information (e.g., credentials) received from the RFID token **742** may be encrypted before being sent over the link **726**.

[**0136**] In **FIG. 7** one cryptographic security boundary is represented by the dashed line **718**. The line **718** represents, in part, that encrypted information may be sent between the security module **708**, the processing component **710** and the data memory **714**. Thus, the information may be sent securely even though the mechanism through which this information is sent (e.g., a data bus **720**) may not be secure.

[**0137**] Encrypted information also may be sent between the integrated circuit **712** and a cryptographic processor **722** in a key manager **724** in the access server **704** via the communication link **726**. In this case, the cryptographic processors may perform key exchange and encryption, decryption and/or authentication operations as necessary to send and receive the encrypted information and provide the information in the clear for internal processing.

[**0138**] In general, the form of protection provided within the system may depend on the requirements of a given application. For example, specifications such as FIPS-140-2 define various levels of security that may be implemented within a system

[**0139**] The security boundary provided by the integrated circuit **712** and the cryptographic boundary **718** may be used to provide a secure mechanism for authenticating a user to access a service. For example, credentials received from the RFID token **742** may be provided directly into an integrated circuit on the input device **716** via RF signals **744**.

[**0140**] Once the information is in the integrated circuit on the input device **716** it may be protected by the physical boundary of the integrated circuit and by a cryptographic boundary (not shown). For example, provisions may be made to ensure that the information does not appear in the clear outside of the integrated circuit. The information may then be securely sent to the access device **702** via what may otherwise be an insecure link **730**.

[**0141**] Credentials received from the input device **716** may be provided directly into the integrated circuit **712** via RF signals **730**. Once the information is in the integrated circuit it may be protected by the physical boundary of the integrated circuit and by the cryptographic boundary **718**. Thus even if rogue software in the system were to gain access to the information outside of the chip **712**, the software would not be able to decrypt it without appropriate key information. However, the key information also may be protected within the integrated circuit **712** and the cryptographic boundary **718**. That is, the key information may not appear in the clear outside of the security boundary. As a result, the credentials may be securely routed to the access server **704**.

[**0142**] Moreover, via this secured mechanism, the access device **702** may reliably authenticate to the access server **704** that a specific RFID token **742** is proximate the input device **716**. First, as discussed above, the credentials may be received in a secure manner. Second, the effective "decision" as to whether the token **742** is adjacent may be made within a security boundary. The security module **708** may then cryptographically sign this information using a secure protocol set up between it and the cryptographic processors **722** of the key manager **724**. Via this signature the access server **704** may be assured that a given message came from a specific processing system (e.g., access device **702**) and that the message has not been compromised. Accordingly, proximity of the token **742** to the input device **716** may be used as a reliable method of authorizing access to a secured service provided by the service provider.

[**0143**] Referring again to **FIG. 8**, an example of operations that may be used to access a service will be described. As represented by block **804**, when the RFID token **742** is within an appropriate range of the input device **716**, the RFID reader **728** will receive an RFID signal **744** from the RFID token **742**. As discussed above, the RFID signal **744** may be received by the input device **716** within a security boundary.

[**0144**] As represented by block **806**, the system **700** may be configured so that any information contained within the broadcast RFID signal may be extracted only within a security boundary. For example, as shown in **FIG. 7**, the RFID reader **728** that extracts the credentials from the RFID signal **744** may be located within an integrated circuit that includes other functionality to protect the credentials. For example, the integrated circuit may include a security module **746** that encrypts/signs the credential (block **808**) to prevent the information from being sent out of the integrated circuit in the clear. Here, the cryptographic processor in the security module **746** may use a private key to encrypt the information. A public key associated with this private key may be published with a certificate from a trusted entity. This certificate serves to verify that the public key is authentic. Cryptographic processing in the access device **702** may then use the public key to verify the signature of information received from the security module **746**.

[**0145**] A similar secure process may then be used to send the information to the access server **704**. A complementary process may be used to securely send information in the other direction across the link **726**.

[0146] Accordingly, after the credential is signed by the cryptographic processor in the security module **708**, the signed credential is sent to the key manager **724** via the link **726** (block **810**). In this way, the information is, in effect, sent over a secured channel (as represented by the corresponding portion of the line **718**) even though the actual data path may not be secure.

[0147] The key manager **724** sends the received information to the cryptographic processor **722** for decryption and/or authentication processing as necessary. The key manager **724** then verifies that the received information indicates that the user is authorized to access the network (block **812**). In some embodiments the access server **704** may include a wireless proximity device (e.g., an RFID reader) and associated processing to enable the credentials to be easily and directly loaded into the access server when a user presents his or her token to the access server. In other embodiments the information may be acquired using a non-dedicated RFID reader. The acquired information may also be loaded into the access server by other means (e.g., downloaded via a communication medium).

[0148] Since the key manager **724** has received an indication via the cryptographic signature associated with the credential that the token **742** is proximate the access device **702**, once the credentials are verified the key manager **724** may be assured that is safe to provide access to the requested service. As discussed above, providing access to a network may involve sending security associations or keys to the access device **702**. These keys may be sent to the access device **702** via the secured channel (cryptographic boundary **718**). Accordingly, the cryptographic processor **722** may encrypt the keys before sending them over the link **726** (block **814**).

[0149] The access device **702** may be configured so that these keys, etc., are decrypted and maintained within the security boundary of the access device **702** (block **816**). For example, the keys may be stored within the integrated circuit **712** (e.g., keys **740**). Alternatively, a cryptographic processor in the security module may use a key (e.g., keys **740**) to encrypt the received keys before storing them in the data memory **714**.

[0150] As represented by block **818**, the access device may then use the received keys to gain access to the network as discussed herein. Again, in some embodiments these keys may only be used in the clear within the security boundary of the access device **702**.

[0151] Additional details of a proximity authentication device are disclosed, for example in commonly-owned U.S. patent application Ser. No. 10/955,806, filed Sep. 30, 2004, the disclosure of which is hereby incorporated by reference herein.

[0152] **FIG. 9** illustrates another embodiment of an access device that provides a secure mechanism for entering credentials. An access device **900** includes a data interface **904** that is located within a security boundary of the access device **900**. For example, the data interface **904** may be located on the same integrated circuit **902** as a security module **906**. As a result, credentials may be directly entered into the security boundary.

[0153] In addition, the security module **906** may use one or more keys (e.g., keys **908**) to encrypt credentials within the security boundary so that the credentials are not provided in the clear outside of the security boundary. Thus, the security module effectively extends the security boundary using cryptographic techniques. For example, the security boundary may be effectively extend (as represented by dashed lines **916**) to an external data memory **914** by encrypting data before it is stored. In addition, the security boundary may effectively extend (as represented by dashed lines **920**) through a communication medium to another cryptographic processing system (not shown).

[0154] In the embodiment of **FIG. 9**, the access device incorporates a wireless interface **910** and an antenna **912** (or another form of a wireless transceiver) to communicate with other wireless devices (e.g., a wireless access point and access server, not shown) via wireless signals **918**. In some embodiments the data communication interface **910** for the access device may advantageously be located on the same integrated circuit as, for example, the security module **906**. The wireless interface may support, for example, 802.11, Bluetooth and/or other wireless communication standards.

[0155] In some embodiments the access device may forward the input information to, for example, an access server to gain access to a service. The information also may be enrolled with a key manager. Thus, as described above, the key manager may compare information received from an access device with the key manager's database of authorized credentials (e.g., fingerprint data). When a match is received, the key manager may provide the associated key(s) to the requesting access device.

[0156] In some embodiments the access server may include an input device and associated processing to enable the information to be easily and directly loaded into the access server. In other embodiments the information may be acquired using a non-dedicated input device (e.g., a sensor). The acquired information may then be loaded into the access server by other means (e.g., downloaded via a communication medium).

[0157] **FIG. 10** illustrates one embodiment of a system **1000** that provides a secure mechanism for a user to enter credentials. A processing system **1002** includes a secure processing system such as a trusted platform module ("TPM") **1004**.

[0158] Typically, the trusted platform module may generate and maintain keys for the processing system. For example, a TPM may provide a set of cryptographic capabilities that enable certain computer functions to be securely executed within the TPM environment (e.g., hardware). To this end the TPM may include one or more cryptographic processors that perform cryptographic operations including, for example, encryption, decryption, authentication and key management. Specifications for a TPM are defined by the Trusted Computing Group organization.

[0159] Typically, to enable access to services managed by the TPM, a user must first enroll his or her credentials with the TPM. This may involve, for example, providing a password to the TPM. To this end, the TPM may include an input device (not shown) that incorporates some of the secure input mechanisms and techniques disclosed in the previous discussions and the discussions that follow (e.g., direct connection, RFID, biometric sensor, keyboard, etc.).

[0160] Then, when a user wishes to access the services managed by the TPM, the user must authenticate himself or

herself to the TPM. This may involve, for example, providing the original password to the TPM. To this end, the processing system **1002** may include an input device **1006** that is connected to the TPM via a link **1008**.

[**0161**] In some embodiments, the link may be routed directly from the input device to the TPM to ensure that data may be securely sent over the link. For example, data from this link may not routed using software routines such as operating system calls. In addition, data from the link may not be stored in data memory that is accessible by other components in the system. For example, the data may not be sent through a software stack and may not be stored in a data memory that is accessed via an internal bus such as a PCI bus. Consequently, input information may be passed to the TPM without being compromised by viruses, hackers, etc., that may have compromised the system. In some embodiments an additional degree of protection may be provided by physically embedding or attaching the input device **1006** within/to the processing system.

[**0162**] Through the use of physical and cryptographic techniques the TPM securely uses and maintains sensitive information such as these credentials within its security boundary. After verifying the credentials (e.g., comparing the received credentials with previously enrolled credentials) within the security boundary, the TPM **1004** may provide the requested access or may facilitate acquiring access to a service from another processing entity.

[**0163**] In some embodiments a user may authenticate himself or herself to the TMP to use keys stored within the security boundary of the TPM. For example, the system of **FIG. 10** may be used to access encrypted data (e.g., an encrypted password) stored in a local data memory (e.g., file storage **1012**). In this case, the TPM **1004** may store cryptographic information (e.g., keys, security associations, etc.) that enables the TPM to decrypt encrypted data. In a typical case, once the user is authenticated, the TPM will use the key within its security boundary, then provide the results to the user. For example, the TPM may return decrypted data (e.g., media content) or signed data to the user. In this way, the keys may be used without exposing the keys in the clear outside the security boundary of the TPM.

[**0164**] In the event there is insufficient storage for the keys in the TPM, the TPM may encrypt the keys and send them to an external data storage component (e.g., file storage **1012**). Thus, even if the encrypted data files in the file storage **1012** may be accessed by other components in the system the security of the encrypted data may be maintained because the keys are encrypted. In other words, sensitive information is only used in the clear within the security boundary of the TPM.

[**0165**] In some embodiments the TPM **1004** may control access to one or more data networks **1022** that are accessed via a network interface **1010**. Here, the TPM **1002** may provide network authentication credentials (e.g., a certificate) to a service provider (e.g., an access point, not shown) connected to a network to authenticate it to the service provider. These network authentication credentials may be securely stored in a data memory (not shown) in the TPM **1004** or stored in encrypted form in the file storage **1012**.

[**0166**] The network interface **1010** may be used to connect to wired and/or wireless network(s). As discussed herein, cryptographic techniques may be used to ensure the security of data transferred between the TPM **1004** and other devices connected to the network. Accordingly, a network connection may be used, for example, to communicate with a key manager to obtain key information (e.g., security associations) and authorization for key usage.

[**0167**] Input device **1014** depicts another embodiment of an input device that may be used to securely provide information (e.g., credentials) to the processing system. The input device **1014** includes a security module **1018** and keys **1020** implemented within a security boundary to provide cryptographic functionality. For example, the security module may be used to encrypt/sign information (e.g., credentials) entered into the input device. In this way, this information may be securely sent (as represented by dashed line **1016**) to the TPM **1004**.

[**0168**] The security module **1018** and the trusted platform module **1004** may include components and perform operations as discussed herein to provide strong authentication and establish a secure channel. For example, a public key and associated certificate may be published for the security module **1018** to enable the TPM to verify the authenticity and the security of the input device using techniques as discussed herein. As a result, a secure channel **1016** may be established between these components such that the security boundary of the TPM may, in effect, be extended to include the input device **1014** and the secure channel.

[**0169**] Since information sent between the components may be secured in this manner, the input device **1014** does not need to be securely connected to the processing system. Thus, the input device **1014** may be advantageously used in applications where the input device is remote from the processing system **1002** and connected to the processing via, for example, a wired or wireless interface such as a network. In addition, the input device may be advantageously used in applications where the input device may be connected to the TPM via an insecure link (e.g., a USB link in a computer).

[**0170**] In some embodiments, the input mechanism (e.g., a key pad, a sensor, etc.) on the input device **1014** may be connected in a secure manner to the security module **1018**. For example, the input mechanism may be located on the same integrated circuit as the security module. In addition, these components may be implemented within a physically protected enclosure. Accordingly, the security boundary of the input device **1014** may include the input mechanism, the security module **1018** and external memory (not shown) that the security module uses to store encrypted information. As a result, the input device **1014** may provide a highly secure mechanism for a user to provide credentials to the TPM **1004**

[**0171**] Referring now to **FIGS. 11-14** selected components and operations of several embodiments of security modules will be discussed in more detail. In some embodiments a security module may provide key protection and management (e.g., enforcing proper usage of keys) required for multiple levels of key material.

[**0172**] In addition, a security module may provide cryptographic processing such as encryption, decryption, authentication, verification and signing for a device that uses cryptographic services (e.g., an access device) in which the security module is installed. For example, a security module

may be implemented in end-user client devices such as cell phones, laptops, etc., that need some form of data security, authentication, etc. In some embodiments the security module may be integrated into previously existing chips (e.g., a main processor) within these devices.

[0173] The security module may be configured as part of and to enforce a security boundary. For example, the security module may be configured to never allow clear text keys to exit, for example, the security module or the chip within which the security module is implemented. As a result, the security module may be safely integrated into other devices or systems regardless of whether the system outside of the security boundary is secure.

[0174] In this way, the security module may provide highly secure and cost effective remote key management for a client device. The security module may provide and/or support any required cryptographic processing. A security boundary is established within the device to securely maintain and use keys and key material. Yet the system may be securely managed by a remote key management system (e.g., a hardware security module, a TPM, etc.) via the security module. Accordingly, a high level of security functionality may be provided for the end-user device using a relatively small security module that has minimal impact on the rest of the device.

[0175] To support this key usage and management scheme, a security module provides mechanisms for securely loading one or more keys into the module, securely storing the keys and securely using the keys. One embodiment of a stateless hardware security module **1100** that provides such mechanisms is depicted in **FIG. 11**.

[0176] The stateless module **1100** includes a master controller **1106** for controlling the overall operation of the module. For example, the controller may control boot operations, key management operations (if applicable) and data and key traffic flow into and out of the module. The controller may comprise, for example, a processor and associated code (e.g., ROM **1108**) and/or a state machine or other hardware. The controller and/or any other component in the stateless module may communicate with other components in the stateless module via an internal bus **1130**.

[0177] In some embodiments the master controller **1106** comprises a RISC processor with ROM code to execute the various commands necessary for the operation of the stateless module. The master controller block also may include the address decoder for each of the slave blocks on the internal bus **1130**. The RISC engine may use a protected portion of a data buffer **1126** for temporary stack and scratch data space.

[0178] A bi-directional external interface **1120** provides a mechanism to send keys and/or data to or receive keys and/or data from the module. For example, the external interface may include registers that may be written to or read by the controller and external devices (e.g., a host) that are connected to the stateless module. In this case, the controller may be configured so that it never writes certain data (e.g., unencrypted keys) to the registers.

[0179] The external data interface **1120** may be used by a local host to read global registers, issue commands and place data into the data buffer **1126** for processing by the stateless module. The external interface may be controlled through a global register block **1122** by the master controller. These global registers may include, for example, command ("CMD"), timer and configuration ("CONFIG.") resisters. The master controller transfers the data between the global registers block and a data buffer memory **1126**.

[0180] The command interface provides a streaming data interface directly into the data input and data output registers. It allows an external FIFO to be used for data input and data output (separate FIFOs). This interface allows the stateless module to be easily embedded into a packet based system.

[0181] In some embodiments, data (e.g., data to be processed or key material) to be encrypted or decrypted may be sent to or sent from the stateless module **1100** via one or more data interfaces. For example a data interface **1102** may be used to send encrypted data or keys (e.g., that were decrypted by the module) to a cryptographic accelerator and vice versa. In addition, a data interface may be connected to an input device (e.g., a sensor) that generates data that needs to be encrypted by the stateless module. This encrypted data may then be sent to an external processing component via the external interface **1120**.

[0182] One or more cryptographic processing blocks perform any cryptographic processing that needs to be done to acquire or use keys or to cryptographically process data flowing though the module. For example, separate processing blocks may be used to perform asymmetric key algorithms such as DSA, RSA Diffie-Hellman (block **1114**), key exchange protocols or symmetric key algorithms such as 3DES, AES (block **1112**) or authentication algorithms such as HMAC-SHA1 (block **1110**). The cryptographic processing block may be implemented, for example, in hardware and/or using a processor that executes code stored in a data memory (e.g., ROM).

[0183] Typically this embodiment includes processing to generate asymmetric keys that are used to establish a secure channel with a remote device and to authenticate information sent from the module to the remote device and vice versa. Here, the private portion of the asymmetric key may be maintained within the security boundary of the chip. In addition, the stateless module also will include a mechanism for exporting the public version of the asymmetric key. For example, the public value may be loaded into the external interface register discussed above so that it may then be read by an external device. The public key value may be read from the stateless module by issuing a public key read command to the stateless module. In response to this command the module returns the public key value and any non-secure configuration information for the device (authorization data, product configuration data, etc.).

[0184] In some embodiments a root, identity key serves as the basis for the asymmetric key. For example, the root key for the module may comprise an asymmetric key pair (secret or private, public) that is used to uniquely identify the stateless module. In some embodiments this key is only used for digital signatures to securely identify the stateless module.

[0185] In some embodiments, one or more keys (e.g., the root, identity key for the module) may be injected into the stateless module. This may be performed, for example, when the chip is manufactured, when the chip is tested, during

manufacture at an OEM (e.g., circuit board manufacturer), during OEM testing or during installation for the end user. This technique may be used to inject symmetric and/or asymmetric keys.

[0186] In some embodiments, the stateless module may generate one or more keys (e.g., the root, identity key) internally. For example, the stateless module may include a random number generator ("RNG") **1118** and other circuitry necessary to generate a key. This embodiment may provide added security in that the generated key may never leave the security boundary of the chip.

[0187] In some embodiments the device identity key comprises a collection of random bits that are used to generate the key material for the long term fixed keys in the stateless module. For example, the RNG **1118** may generate a random number using the internal random number value as a secret initialization seed. The number of bits in the initialization seed may be determined by the amount of key entropy required for the system.

[0188] In some embodiments the value from the random number generator **1118** may not be used directly. For example, it may be post processed using the SHA-1 block **1110** by the master controller before internal usage and before exposing the number external to the stateless module as a random value. The master controller may maintain a cache of post processed random bits (for key generation and for signing) in the data buffer **1126**.

[0189] The random number generator **1118** may be a "true" random source. For example, it may utilize free running oscillators to capture thermal noise as the source of randomness.

[0190] The stateless module also may include a privacy (or confidentiality) asymmetric key pair that may be used for transferring secure content to the stateless module device via an intermediate insecure third party such that the third party does not have access to the key material. In some embodiments the confidentiality key is only used to decrypt key material within the stateless module.

[0191] The above keys (e.g., the root, identity key, etc.) may be stored in a nonvolatile data memory ("NVM") **1116**. The NVM may comprise, for example, a one-time programmable ("OTP") memory or battery backed memory (BBMEM) that is located on-chip or off-chip.

[0192] In some embodiments an on-chip OTP memory (as shown in **FIG. 11**) may provide certain advantages. For example, in this case the keys may be physically protected within the device so that they cannot be easily altered or observed. In addition, since the use of the keys may be confined within the chip, the keys may not appear in the clear outside of the chip. Moreover, this OTP and stateless module combination may then be implemented using a standard CMOS process. As a result, the stateless module may be readily integrated into a variety of conventional chips that are used in end-user and other devices. Such a combination may provide a very cost effective security solution.

[0193] Examples of architectures and implementations of OTP memory that may be advantageously implemented in CMOS are described in, for example, U.S. Pat. Nos. 6,525,955, 6,693,819, 6,700,176 and 6,704,236 and U.S. patent application Ser. No. 09/739,952, filed Dec. 20, 2000, the disclosure of each of which is hereby incorporated by reference herein.

[0194] The OTP may be programmed by the master controller **1106** via a programming interface in conjunction with an external programming signal VPP. The master controller may ensure (via local hardware enforcement) that the device keys, authorization and configuration data can be programmed once and only once.

[0195] The key-encryption-key ("KEK") cache **1124** is a separate memory block sized based on the required number of KEKs in the system. Typically, it is large enough to hold the session private key and a single asymmetric group key.

[0196] The KEK Cache **1124** may be protected in hardware during the execution of any command that does not require a KEK key. For example, a signal from the global registers may be provided to the KEK cache to indicate that the command register is locked, active and contains a command that requires a KEK. Some KEK cache locations are contained in the NVM block that is used to implement the long term keys for the stateless module.

[0197] The application key cache **1104** may be used by the master controller to provide encryption and decryption storage for the internal acceleration cores (such as the public key core **1114** or the 3DES core **1112**). The application key cache may enforce key lifetime expiration when the keys are used by either the stateless module commands or the application key cache interface.

[0198] In general, the performance, size and function of the blocks discussed above may be scaled to meet the demands of the system. For example, the basic cryptographic functions that implement the secure channel back to the key manager to transfer and process key material (and/or policy) may be provided at minimal processing performance levels.

[0199] The cryptographic accelerators contained within the stateless module can be used for application data processing when they are not being used for key management functions. For example, a stateless module for an e-commerce application may be used to protect RSA private keys. Here, the public key acceleration required for the secure channel is typically minimal (less than 10 operations/sec). Consequently, any spare processing capacity (e.g., idle cycles of a processor) may be used for other operations.

[0200] In contrast, public key acceleration required for a typical e-commerce accelerator is relatively high (greater than 500 operations/sec). Applications such as this may require the use of cryptographic accelerators that are specially designed to perform cryptographic operations at a high rate of speed.

[0201] One or more cryptographic accelerators may be attached directly to the stateless module via the application key cache interface **1102**. Typically, the application key cache interface for the add-on cryptographic acceleration processing is maintained within the security boundary. For example, the stateless module and the cryptographic accelerators may be implemented on the same chip. In this manner, the cleartext keys are not allowed to leave the security boundary which also includes the public key accelerator. However, the external application may use the public

key accelerator as it normally would by simply referencing the appropriate RSA private key stored in the stateless module.

[0202] The application key cache **1104** also may store key material that may be used by external cryptographic acceleration processors. For example, the cache **1104** may store decrypted application keys (e.g., the RSA private key for an application executing on the device that contains the stateless module).

[0203] The stateless module enforces key policy for keys used within the remote client. The key policy may be set by the key manager for all keys that are delivered to the stateless module. The key policy indicates how the key can be used by the stateless module. In addition to usage policy, the stateless module can enforce a lifetime for keys. Typically, a key lifetime is a relative time from the time at which the key is loaded into the stateless module. The key manager can use the multiple levels of key hierarchy and the lifetime policy enforcement to ensure that keys are used properly and are revocable at the stateless module.

[0204] A security assurance logic block **1128** protects the stateless module from system security attacks. To this end, several system monitors may be coupled with the other components in the stateless module and/or the chip (and/or the system) within which the stateless module resides.

[0205] In some embodiments, the protection circuits trigger a reset of the stateless module when an attack is detected. This reset may wipe out all transient information in the stateless module. For example, all key cache locations may be cleared. An interrupt may be provided to the local host with information on which protection mechanism triggered the reset.

[0206] A low frequency protection circuit ensures that the operating frequency of the stateless module does not fall below given threshold. This ensures that the time tick register value can not be compromised within the limit of a reference frequency. In addition to protecting the time tick value, the low frequency protection circuit makes it more difficult to implement successful dynamic attacks that attempt to read values within the stateless module while it is operating. In this case, the higher the threshold value, the better protection that is provided.

[0207] An operating point protection circuit may be provided to ensure that all logic within the stateless module operates as designed for all process, voltage and temperature conditions (or across all operating points). The protection circuit helps ensure that an attacker cannot change the operating point such that a timing path is violated in the stateless module.

[0208] A watchdog timer block may be used during processing to ensure that command execution completes within an expected period of time. The timer is set by the master controller whenever a command (or sub-command such as a public key operation) is started. The set time is based on the expected maximum command length. If the watchdog timer reaches zero a reset is issued to the stateless module. The watchdog timer cannot be turned off and must be written periodically by the master controller to avoid clearing the stateless module. The watchdog timer may be frozen when the stateless module is taking command input from the host.

[0209] A reset monitor provides protection against multiple reset attacks. The reset monitor uses a timer based on the time tick register increment that requires at least one tick before allowing more than, for example, sixteen resets to occur. If more than sixteen resets occur within the time tick, the stateless module will require at least two time ticks before releasing the sixteenth reset. The reset protection is disabled until the NVM has been properly programmed. For example, it may be disabled during manufacturing tests.

[0210] A hardware protection mechanism may be provided for entering and exiting a secure state while the stateless module transitions between enabling/disabling the external interface. The stateless module boots to a secure state with the external interface disabled. That is, the interface is locked out by hardware. Once reset processing and self-tests have completed, the master controller sequences through a series of commands to exit the secure state and enter a USER state. In some embodiments these commands require execution of a predefined set of sequential instructions be written to non-sequential addresses.

[0211] The hardware tracks the number of clocks it takes to execute each step of the sequence and ensures that these commands occur in the required order to the required address at exactly the right clock cycle. After the exit logic has completed, the mode is set via hardware to USER mode. In USER mode, the hardware locks out master controller access to all of the internal blocks except the data buffer and the data input/output registers (only blocks that are required to move data into the device).

[0212] Once the command has been moved into the data buffer, the master controller sequences a series of commands to return to the secure state. This sequence is again tracked and enforced via the hardware block to enter into secure mode. It also ensures via hardware that the master controller enters the secure mode with the proper entry address.

[0213] The master controller ROM **1108** may be programmed using an extra bit to indicate which instructions are valid code entry and code exit points. The instruction code entry/exit points are enforced in hardware whenever the master controller takes a non-sequential code fetch. This mechanism helps to ensure that it will be difficult for an attacker to get the master controller to bypass certain portions of code. As a result, it may be virtually impossible to successfully attack the module by causing random jumps in the program execution.

[0214] To reduce cost and die space, the stateless module may not handle processing related to communication protocols. Instead, the requirements of communication protocols may be handled by an associated device driver (or integrated processor).

[0215] In an alternative embodiment, the stateless module may be assigned long-term keys. In this case, the stateless module may not need to interface with a head-end server (e.g., key manager).

[0216] Referring now to **FIG. 12**, an example of operations that may be performed by one embodiment of a stateless module will be discussed. As represented by block **1202**, when the stateless module is initialized for the first time after manufacture (e.g., during final test of the chip), the master controller may cause the random number generator

1118 to generate a random number that is provided as a seed to a cryptographic processor that generates a public-private key pair.

[**0217**] The master controller stores the private (identity) key in the nonvolatile memory **1116** and never exports this key outside of the security boundary of the module (block **1204**). For example, in some embodiments the key never leaves the chip within which the stateless module resides. In some embodiments this key is encrypted before being stored in off-chip non-volatile memory.

[**0218**] The stateless module also stores the corresponding public key and, upon request, exports the public key (block **1206**) so that the device manufacturer (or some other trusted entity) may publish the public key along with a certificate to a public server.

[**0219**] The stateless module may then be deployed in a computing device that can connect to another device (e.g., a key manager) via a network or some other link. As represented by block **1208**, the stateless module may use its private key to establish a secure communication channel with, for example, a security module (e.g., a key manager) that has access to the stateless module's public key.

[**0220**] As represented by block **1210** the key manager may send keys to the stateless module via the secure communication channel. For example, the key manager and stateless module may negotiate to obtain additional keys that may be used to provide secure communications between the two components. In addition, the key manager may send keys to a remote client via the stateless module. For example, the key manager may generate a private session key (Ka-priv) for a client that incorporates the stateless module. As discussed above, the key manager may encrypt this key using the stateless module's public key (Kdc-pub) or some negotiated key before sending it to the client.

[**0221**] As represented by block **1212**, the keys are decrypted within the security boundary associated with the stateless module. For example, cryptographic processors in the stateless module may decrypt these keys. Alternatively, another cryptographic processor located on the same chip as he stateless module may decrypt the keys.

[**0222**] As represented by block **1214**, the stateless module may then use the keys within the security boundary. For example, cryptographic processors in the stateless module may use these keys to decrypt other keys (e.g., session keys). In addition, the stateless module may enforce key policy within the security boundary (block **1216**).

[**0223**] In some embodiments, as represented by block **1218**, the stateless module may provide keys to one or more cryptographic accelerators within the security boundary. For example, the cryptographic accelerators may be located on the same chip as the stateless module.

[**0224**] Referring now to **FIG. 13**, one embodiment of a stateless secure link module **1300** will be discussed in detail. This embodiment includes, in general, a subset of the functionality of the embodiment of **FIG. 11**. In particular, this embodiment only provides data encryption, decryption, etc. using a symmetric key. One advantage of this configuration is that it may be implemented in other devices with even less impact on the cost and the size of the devices.

[**0225**] In a typical application the embodiment of **FIG. 13** is used to take data that originates from an input device and securely provide that data to a recipient device that uses the data (e.g., an access device or an access server). This process may involve encrypting the data so it does not appear in clear text and/or signing the data to certify to the recipient device that the data originated from a specific input device.

[**0226**] For example, the stateless module may be integrated into a chip for a sensor (e.g., a biometric sensor such as a fingerprint reader). Here, the stateless module may be used to sign and/or encrypt the information generated by the sensor. The stateless module may then securely send the information to a recipient device that uses the information. In this case, the recipient device may use a fingerprint comparison as a means to control access to data or a service.

[**0227**] In some embodiments the sensor data is always maintained within a security boundary. First, by incorporating the stateless module into the sensor chip, the information may be encrypted before it leaves the hardware boundary of the chip. Second, the stateless module may establish a secure channel with the recipient device through a symmetric key exchange. In this way, the information may be securely sent to the recipient device. Third, the recipient device may be secured in a conventional manner or using techniques as described herein.

[**0228**] As an example of the latter scenario, the recipient device may include a stateless module as described above in conjunction with **FIG. 11**. In this case, the recipient device may use other keys to, for example, securely send the information to a remote system. One example of such a remote system is a network access device that enables access to a network based on the user's credentials such as the user's fingerprint.

[**0229**] In other embodiments, it may only be necessary to establish that the data originated from a specific input device. For example, the system may make other provisions to ensure that a copied fingerprint data stream is not being replayed at a later time. In this case, it may be unnecessary to encrypt the information. All that may be needed here is an assurance that the information is being sent by a specific sensor. In this case, adequate security may be provided by simply signing the data.

[**0230**] To provide a solution that is cost effective for a variety of input devices, the stateless module of **FIG. 13** has a reduced set of functionality as compared to, for example, the embodiment of **FIG. 11**. The stateless module includes a master controller **1306** and an external interface **1312** to enable the asymmetric key operations that are performed when the secure link is initially established with, for example, a key manager. Thus, the controller **1306** includes circuitry to generate and verify the validity of its keys. In addition, the module may include assurance logic **1320** similar to that discussed above.

[**0231**] However, because the module only uses a single symmetric key, much of the functionality depicted in **FIG. 11** is not provided in the embodiment of **FIG. 13**. For example, the module does not need to provide management capabilities (e.g., enforcement of key policy) and data storage (e.g., application key cache) for extra keys. Also, the non-volatile ROM ("NVROM") **1310** may be smaller since it may only store, for example, an identity key and a symmetric key.

[0232] Moreover, as this module only performs symmetric cryptographic processing on data from a data streaming interface, some or all of the dedicated cryptographic processors shown in **FIG. 11** (e.g., the public key processing and 3DES) may not be needed. For example, the module only performs the asymmetric key operations once after it boots up. In addition, the stateless module does not need to verify the authenticity of the recipient of the data. Accordingly, the remaining cryptographic processing operations may be performed by the master controller **1306**. In this case, the application code for cryptographic algorithms (e.g., DH, DSA, 3DES, AES) may be stored in a ROM **1308**.

[0233] The embodiment shown in **FIG. 13** may secure an incoming data stream (DI) by signing it using the SHA-1 algorithm. Accordingly, a separate processing block **1304** may be provided for this operation. The signed output of this processing **30** block provides a data stream (DO) that is sent to the recipient device via a data interface **1302**. In an embodiment that also encrypts the data stream, a dedicated processing block (not shown) may be provided to implement, for example, a symmetric encryption algorithm.

[0234] Referring now to **FIG. 14**, an example of operations that may be performed by one embodiment of a stateless secure link module will be discussed. As represented by blocks **1402-1408**, a stateless secure link module generates a public-private key pair, stores the private (e.g., identity) key in nonvolatile memory within the security boundary, exports the public key and establishes a secure communication channel with, for example, a key manager.

[0235] As represented by block **1410** the key manager may send symmetric keys to the stateless secure link module via the secure communication channel. For example, the key manager may send symmetric keys that are used to encrypt and/or sign data that the stateless secure link module receives from an input device. The cryptographic processors may then decrypt these keys (block **1412**) and store the decrypted keys (block **1414**) within the security boundary associated with the stateless secure link module.

[0236] As represented by block **1416**, the stateless module may receive data to be encrypted from an input component. As discussed above the input component may be, for example, a biometric sensor, a sensor for a camera, etc., or any other device that needs data to be authenticated or securely transmitted to another (e.g., remote) device (e.g., the recipient device).

[0237] As represented by blocks **1418**, the stateless module uses the symmetric keys within the security boundary to encrypt the data. Then, as represented by block **1420**, the stateless module sends the encrypted data to the remote device.

[0238] In some embodiments the symmetric key may be injected into the stateless module during manufacture (e.g., during chip test). In this case, all or a portion of the external interface **1312**, the RNG **1316** and the asymmetric key processing circuitry may not be needed. Accordingly, in some embodiments a stateless module may simply include a relatively small master controller for injecting the symmetric key and perform other basic operations, a nonvolatile memory, a data buffer memory, a cryptographic processor for the symmetric key operations and optionally, assurance logic.

[0239] Additional details of security modules are disclosed, for example, in commonly-owned U.S. patent application Ser. No. 10/_____ , filed Jun. 21, 2005, entitled STATELESS HARDWARE SECURITY MODULE, Attorney Docket No. 53028/SDB/B600, the disclosure of which is hereby incorporated by reference herein.

[0240] It should be appreciated that the various components and features described herein may be incorporated in a system independently of the other components and features. For example, a system incorporating the teachings herein may include various combinations of these components and features. Thus, not all of the components and features described herein may be employed in every such system.

[0241] Different embodiments of the invention may include a variety of hardware and software processing components. In some embodiments of the invention, hardware components such as controllers, state machines and/or logic are used in a system constructed in accordance with the invention. In some embodiments code such as software or firmware executing on one or more processing devices may be used to implement one or more of the described operations.

[0242] Such components may be implemented on one or more integrated circuits. For example, in some embodiments several of these components may be combined within a single integrated circuit. In some embodiments some of the components may be implemented as a single integrated circuit. In some embodiments some components may be implemented as several integrated circuits.

[0243] The components and functions described herein may be connected/coupled in many different ways. The manner in which this is done may depend, in part, on whether the components are separated from the other components. In some embodiments some of the connections represented by the lead lines in the drawings may be in an integrated circuit, on a circuit board and/or over a backplane to other circuit boards. In some embodiments some of the connections represented by the lead lines in the drawings may comprise a data network, for example, a local network and/or a wide area network (e.g., the Internet).

[0244] The signals discussed herein may take several forms. For example, in some embodiments a signal may be an electrical signal transmitted over a wire, light pulses transmitted through air or over an optical fiber or electromagnetic (e.g., RF or infrared) radiation transmitter transmitted through the air.

[0245] A signal may comprise more than one signal. For example, a signal may consist of a series of signals. Also, a differential signal comprises two complementary signals or some other combination of signals. In addition, a group of signals may be collectively referred to herein as a signal.

[0246] Signals as discussed herein also may take the form of data. For example, in some embodiments an application program may send a signal to another application program. Such a signal may be stored in a data memory.

[0247] The components and functions described herein may be connected/coupled directly or indirectly. Thus, in some embodiments there may or may not be intervening devices (e.g., buffers) between connected/coupled components.

[0248] A wide variety of devices may be used to implement the data memories discussed herein. For example, a data memory may comprise flash memory, one-time-programmable (OTP) memory or other types of data storage devices.

[0249] In summary, the invention described herein generally relates to an improved authentication system and method. While certain exemplary embodiments have been described above in detail and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive of the broad invention. In particular, it should be recognized that the teachings of the invention apply to a wide variety of systems and processes. It will thus be recognized that various modifications may be made to the illustrated and other embodiments of the invention described above, without departing from the broad inventive scope thereof. In view of the above it will be understood that the invention is not limited to the particular embodiments or arrangements disclosed, but is rather intended to cover any changes, adaptations or modifications which are within the scope and spirit of the invention as defined by the appended claims.

What is claimed is:

1. An authentication method comprising:

receiving authentication data at an input device;

cryptographically processing the authentication data at the input device;

transmitting the cryptographically processed authentication data to an access device;

processing the transmitted authentication data at the access device;

transmitting the processed authentication data to a service provider.

2. The method of claim 1 wherein cryptographically processing includes at least one of authenticating and encrypting.

3. The method of claim 1 wherein cryptographically processing comprises using a symmetric key provided by the access device.

4. The method of claim 1 wherein cryptographically processing comprises using a symmetric key injected into the input device during manufacture of the input device.

5. The method of claim 1 comprising establishing cryptographic link between the input device and the access device.

6. The method of claim 1 comprising performing asymmetric key operations between the input device and the access device.

7. The method of claim 1 comprising generating an asymmetric key pair within the input device.

8. The method of claim 1 comprising generating an asymmetric key pair within a security boundary of the input device.

9. The method of claim 1 wherein the authentication data is received within a security boundary of the input device.

10. The method of claim 1 wherein the input device comprises a sensor.

11. The method of claim 1 wherein the input device comprises a proximity authentication system.

12. The method of claim 1 wherein processing the transmitted authentication data comprising authenticating the transmitted authentication data.

13. The method of claim 1 wherein the service provider grants access to at least one service in response to the transmitted processed authentication data.

14. The method of claim 1 wherein the service provider enables access to a network in response to the transmitted processed authentication data.

15. A secure data processing system comprising:

an input device adapted to receive authentication data, cryptographically process the authentication data and transmit the cryptographically processed authentication data over a medium; and

an access device adapted to receive the transmitted authentication data, process the received authentication data and transmit the processed authentication data to a service provider.

16. The system of claim 15 wherein cryptographically process includes at least one of authenticating and encrypting.

17. The system of claim 15 wherein cryptographically process comprises using a symmetric key provided by the access device.

18. The system of claim 15 wherein cryptographically process comprises using a symmetric key injected into the input device during manufacture of the input device.

19. The system of claim 15 wherein the input device and the access device are adapted to establish a cryptographic link between the input device and the access device.

20. The system of claim 15 wherein the input device and the access device are adapted to perform asymmetric key operations between the input device and the access device.

21. The system of claim 15 wherein the input device is adapted to generate an asymmetric key pair.

22. The system of claim 15 wherein the input device is adapted to generate an asymmetric key pair within a security boundary of the input device.

23. The system of claim 15 wherein the authentication data is received within a security boundary of the input device.

24. The system of claim 15 wherein the input device comprises a sensor.

25. The system of claim 15 wherein the input device comprises a proximity authentication system.

26. The system of claim 15 wherein processing the transmitted authentication data comprising authenticating the transmitted authentication data.

27. The system of claim 15 wherein the service provider grants access to at least one service in response to the transmitted processed authentication data.

28. The system of claim 15 wherein the service provider enables access to a network in response to the transmitted processed authentication data.

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