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Kurn et al.

(54) SCALABLE COMPUTER SYSTEM USING REMOTE AGENTS TO MANIPULATE CRYPTOGRAPHIC KEYS

(76) Inventors: **David Michael Kurn**, Mountain View, CA (US); **Kent Adams Salmond**, Los Gatos, CA (US); **Robert A. Panero**, San Carlos, CA (US)

Correspondence Address:
OPPENHEIMER WOLFF & DONNELLY
P. O. BOX 10356
PALO ALTO, CA 94303 (US)

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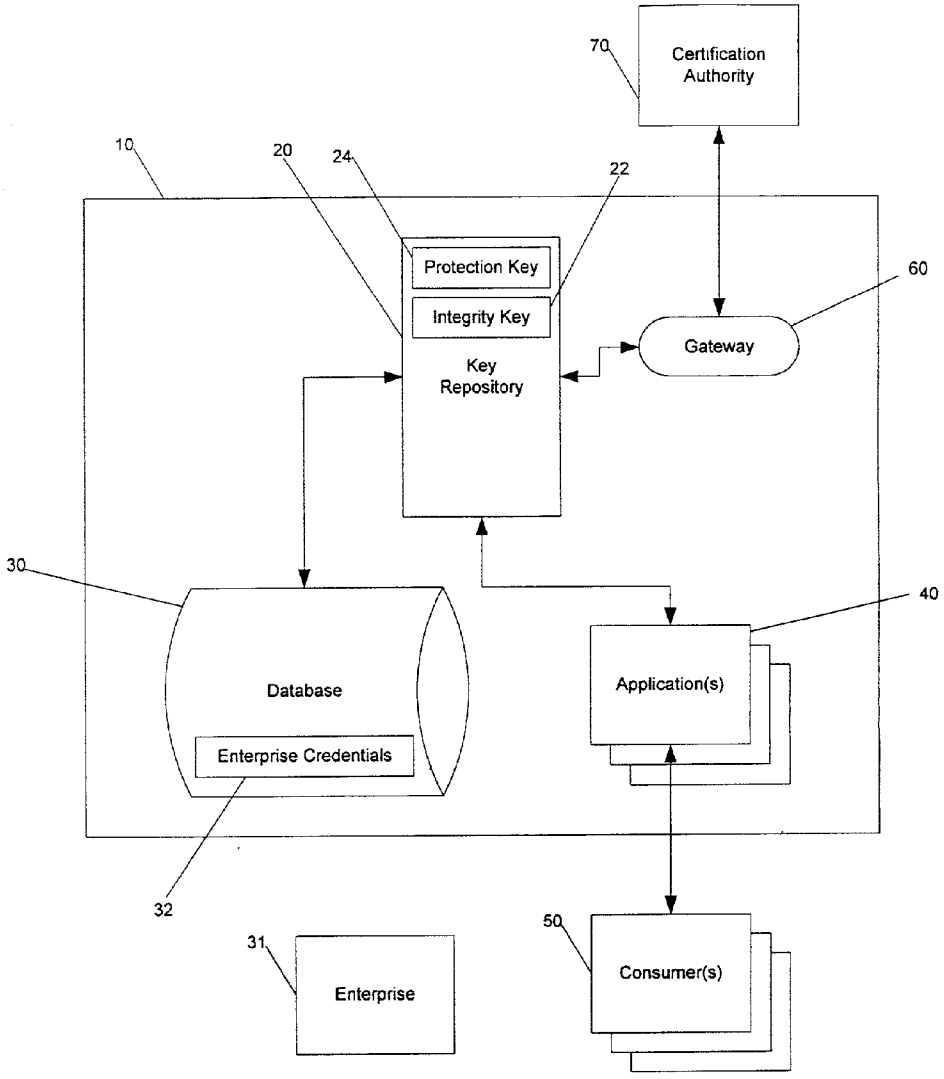
(57) **ABSTRACT**

In large computer application environments supporting secure enterprise applications, it is often necessary to distribute the environment among multiple systems in diverse locations, and yet share and maintain a set of keys and other sensitive information securely. This invention describes a method to accomplish this, by positioning in each remote site a trusted local agent, and establishing a secure and authenticated communications link between this remote agent and the master system. This remote agent limits the distribution of sensitive information to authorized applications, thus enforcing the security policy of the enterprise.



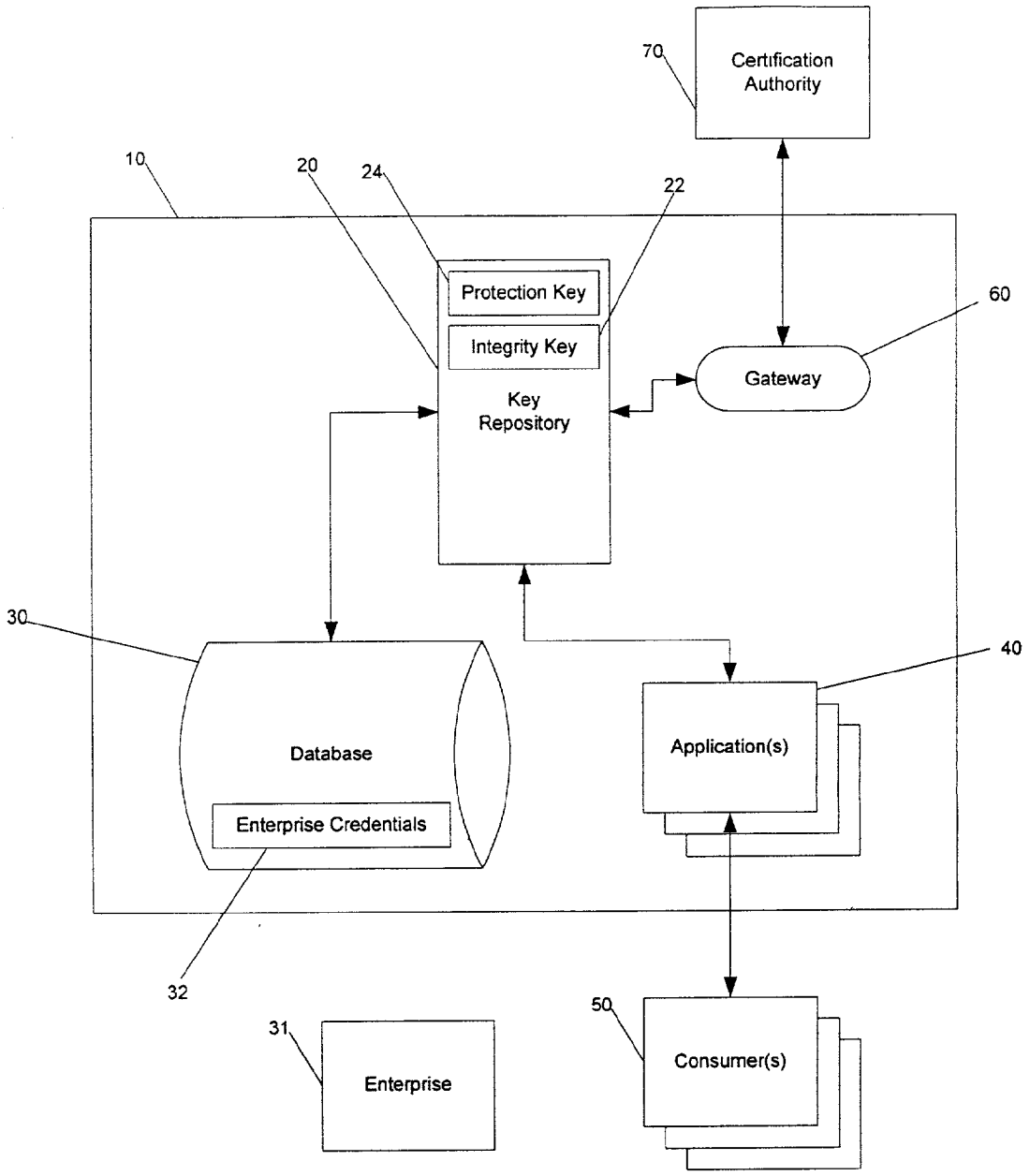

70
Certification Authority
10
20
24
22
Protection Key
Integrity Key
Key Repository
60
Gateway
30
40
Database
Enterprise Credentials
Application(s)
32
31
Enterprise
50
Consumer(s)

Figure 1

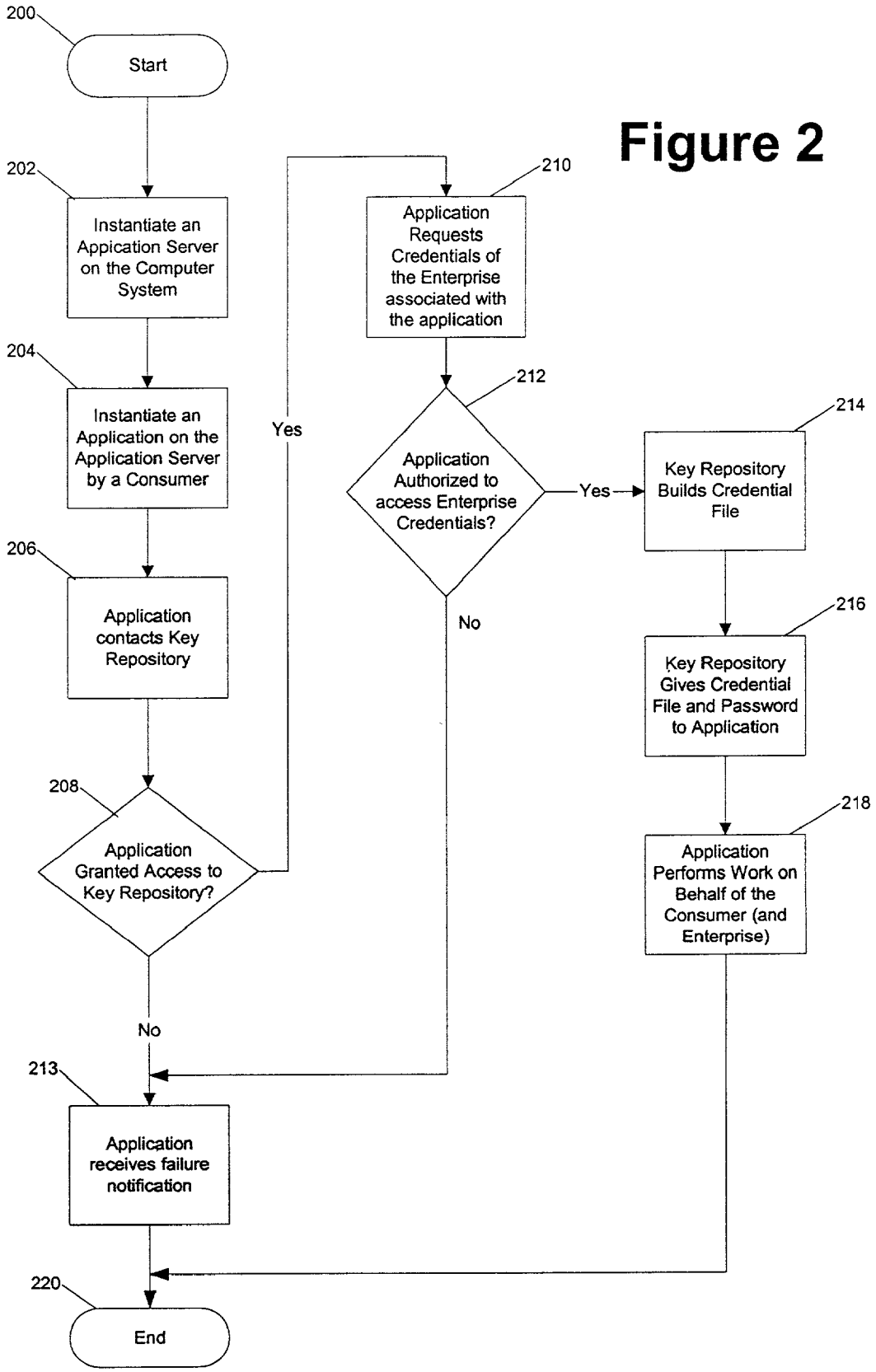

200
Start
202
Instantiate an Appication Server on the Computer System
204
Instantiate an Application on the Application Server by a Consumer
206
Application contacts Key Repository
208
Application Granted Access to Key Repository?
Yes
No
210
Application Requests Credentials of the Enterprise associated with the application
212
Application Authorized to access Enterprise Credentials?
Yes
No
214
Key Repository Builds Credential File
216
Key Repository Gives Credential File and Password to Application
218
Application Performs Work on Behalf of the Consumer (and Enterprise)
213
Application receives failure notification
220
End

Figure 2

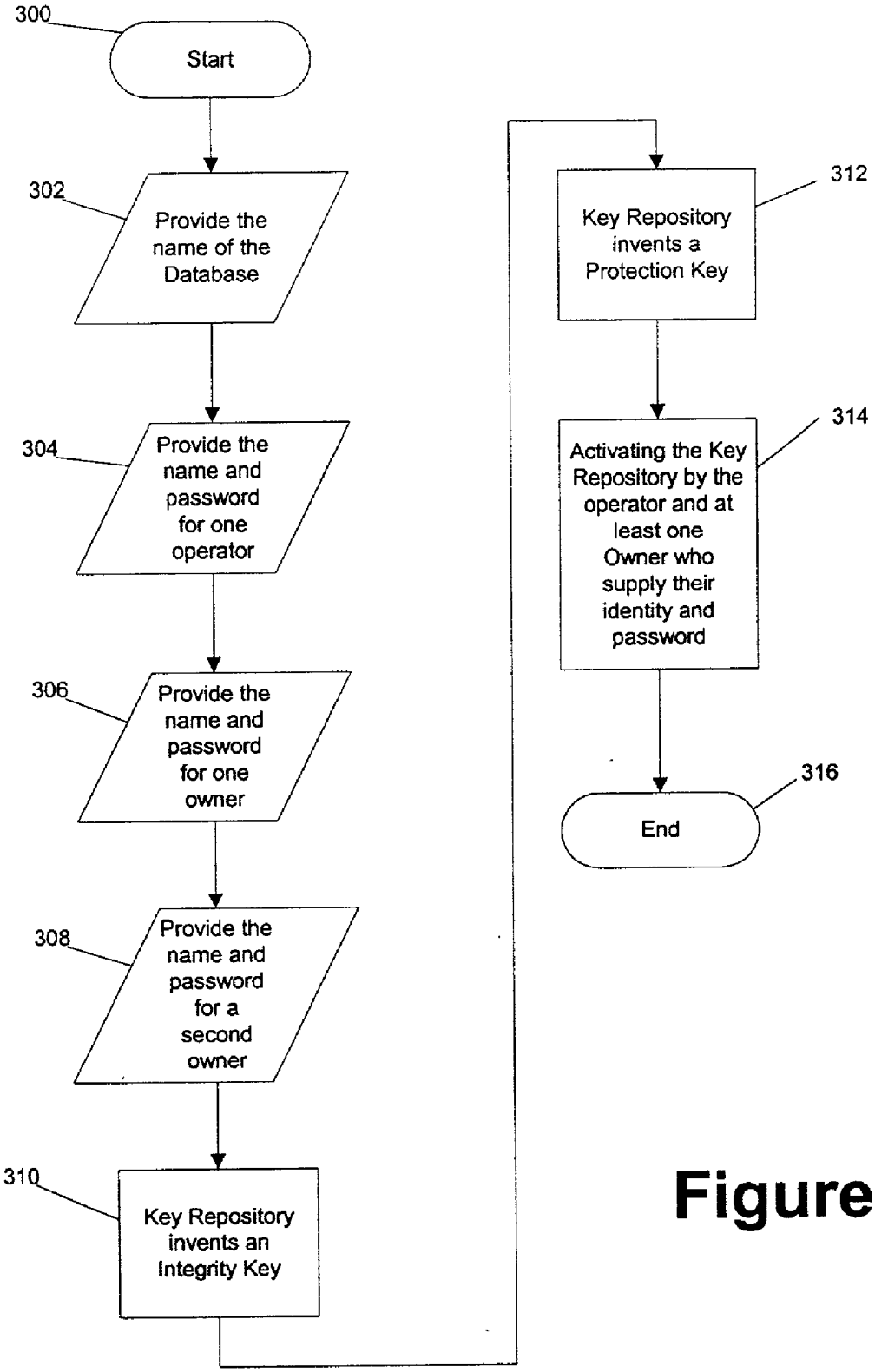

300
Start
302
Provide the name of the Database
304
Provide the name and password for one operator
306
Provide the name and password for one owner
308
Provide the name and password for a second owner
310
Key Repository invents an Integrity Key
312
Key Repository invents a Protection Key
314
Activating the Key Repository by the operator and at least one Owner who supply their identity and password
316
End

Figure 3

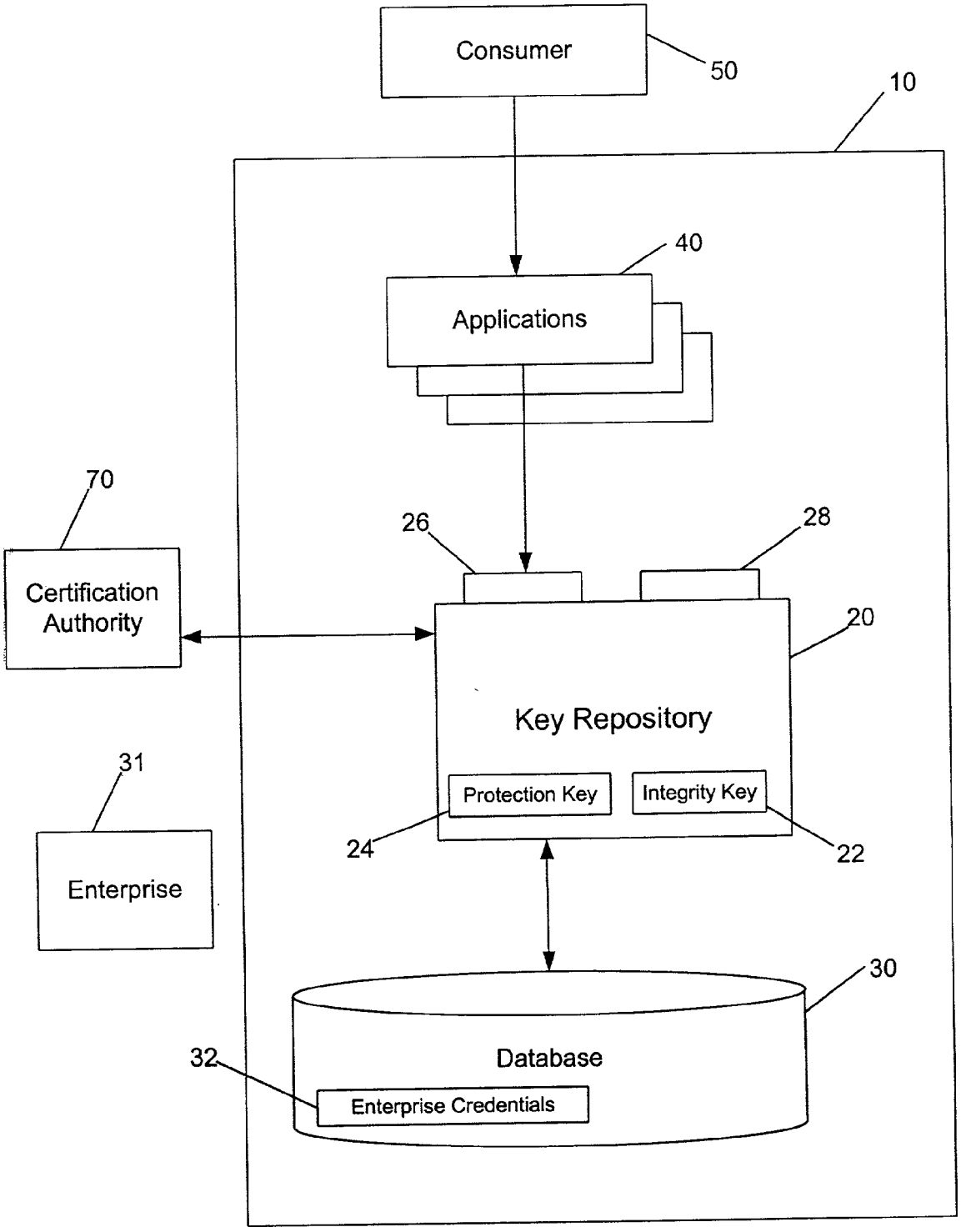

Consumer
50
10
40
Applications
70
Certification Authority
26
28
20
Key Repository
Protection Key
Integrity Key
24
22
31
Enterprise
30
Database
32
Enterprise Credentials

Figure 4

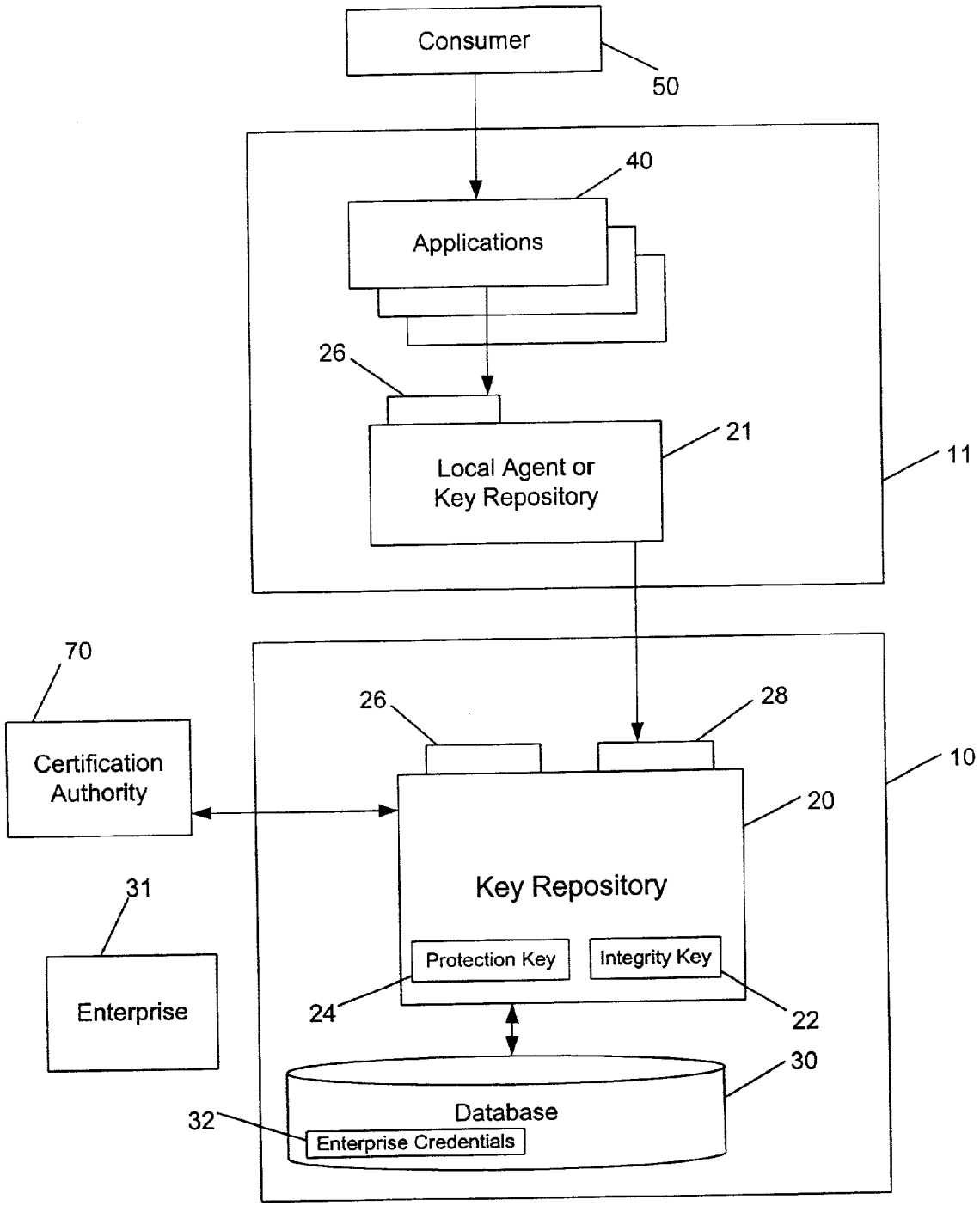

Consumer
50
40
Applications
26
21
Local Agent or
Key Repository
11
70
Certification
Authority
26
28
10
20
Key Repository
31
Protection Key
Integrity Key
Enterprise
24
22
30
Database
32
Enterprise Credentials

Figure 5

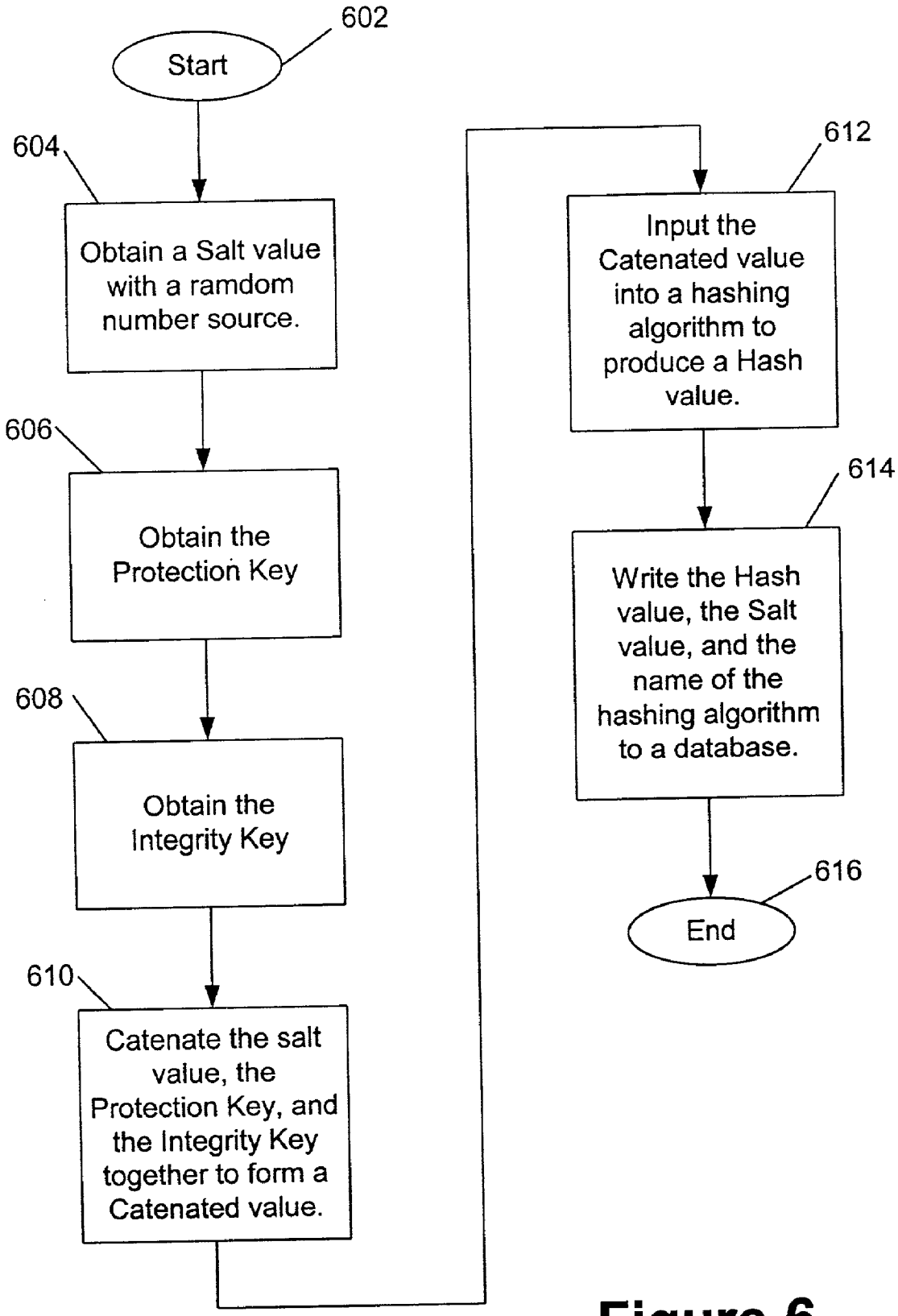

602
Start
604
Obtain a Salt value with a ramdom number source.
606
Obtain the Protection Key
608
Obtain the Integrity Key
610
Catenate the salt value, the Protection Key, and the Integrity Key together to form a Catenated value.
612
Input the Catenated value into a hashing algorithm to produce a Hash value.
614
Write the Hash value, the Salt value, and the name of the hashing algorithm to a database.
616
End

Figure 6

SCALABLE COMPUTER SYSTEM USING REMOTE AGENTS TO MANIPULATE CRYPTOGRAPHIC KEYS

RELATED APPLICATIONS

[0001] This application is related to and incorporates herein by reference U.S. applications entitled as Follows:

[0002] "Scalable Computer System Using Password-Based Private Key Encryption" (Docket No. 20206.30 (P003014)), Ser. No._____, Filed _____;

[0003] "Method And Apparatus For Enforcing The Separation Of Computer Operations And Business Management Roles In A Cryptographic System" (Docket No. 20206.31 (P003015)), Ser. No. _____, Filed _____;

[0004] "Software Process Pre-Authorization Scheme For Applications On A Computer System" (Docket No. 20206-32 (P00-3016)), Ser. No. _____, Filed _____;

[0005] "Multiple Cryptographic Key Linking Scheme On A Computer System" (Docket No. 20206-33 (P00-3017)), Ser. No. _____, Filed _____;

[0006] "Centralized Cryptographic Key Administration Scheme For Enabling Secure Context-Free Application Operation" (Docket No. 20206-34 (P00-3416)), Ser. No. _____, Filed _____;

[0007] "Method And Apparatus For Cryptographic Key Rollover During Operation" (Docket No. 20206-36 (P00-3418)), Ser. No. _____, Filed _____;

[0008] "Computer System Having An Autonomous Process For Centralized Cryptographic Key administration" (Docket No. 20206-37 (P00-3019)), Ser. No. _____, Filed _____; and

[0009] "Computer System Employing A Split-Secret Cryptographic Key Linked To A Password-Based Cryptographic Key Security Scheme" (Docket No. 20206-38 (P00-3420)), Ser. No. _____, Filed _____.

BACKGROUND OF THE INVENTION

[0010] 1. Field of the Invention

[0011] The present invention is related to computer security. More specifically, the present invention is related to cryptographic systems on computer servers.

[0012] 2. Description of the Related Art

[0013] E-Commerce

[0014] The advent of the Internet has spawned a new means for conducting business. Commerce that is conducted online, such as via the Internet or virtual private networks, is called e-commerce. E-commerce mimics many of the steps of regular commerce. However, because of the nature of cyberspace, the parties may never have met and may never meet. To accommodate business transactions where the parties never meet or know each other, various schemes have been devised to ensure secure and verifiable business transactions.

[0015] The security of the e-commerce transaction is accomplished through encryption schemes. The authenticity and other necessary aspects of commerce are handled through trust relationships. Often, these trust relationships are implemented through trusted third parties and are erected as part of the online business infrastructure.

[0016] Computing systems evolved away from mainframe computers in the 1960's and 1970's to a distributed environment consisting mainly of personal computers in the 1980's and early 1990's. However, with the advent of the Internet, powerful servers (descendants of the old mainframe computers) have regained their former importance. Internet-connected servers now run software applications for client systems and perform business-to-business transactions and business-to-consumer transactions. In many cases, these transactions include sensitive information, which must be protected against unwanted exposure (privacy) or modification (integrity), or both. In some cases, there's a requirement that there be strong evidence of an event having taken place (non-repudiation), to further the resolution of disputes. People working in the field of cryptography have developed various schemes and methods have to provide such facilities. One of the crucial infrastructures of online business is trust. A trust relationship can be erected using computer servers (and clients) that are equipped with software encryption applications.

[0017] A typical prior art public key encryption scheme is the RSA scheme, which is described in U.S. Pat. No. 4,405,829 to Rivest et al; R. L. Rivest, A. Shamir, and L. M. Adleman, "A Method for Obtaining Digital Signatures and Public-Key Cryptosystems," Communications of the ACM, v. 21, n. 2, February 1978, pp. 120-126; "R. L. Rivest, A. Shamir, and L. M. Adleman, "On Digital Signatures and Public Key Cryptosystems," MIT Laboratory for Computer Science, Technical Report, MIT/LCS/TR-212, January, 1979. The RSA scheme is used both for encryption and digital signatures. The RSA scheme is often combined with other technologies to provide privacy, integrity, and non-repudiation. Cryptographic systems, and the terminology used in the discipline, are described in "Applied Cryptograpy" by Bruce Schneier (John Wiley & Sons, Inc., New York, 1996).

[0018] RSA Scheme

[0019] According to Bruce Schneier, "RSA gets its security from the difficulty of factoring large numbers. The public and private keys are functions of a pair of large prime numbers (100 to 200 digits or even larger). Recovering the plaintext from the public key and the ciphertext conjectured to be equivalent to factoring the product of the two primes." Bruce Schneier, "Applied Cryptography" Second Edition, John Wiley & Sons, Inc., New York, 1996, pp. 467.

[0020] Under the RSA scheme, to generate the two keys, one chooses two random large prime numbers, p and q. For maximum security, one chooses both p and q to be equal in length. Next, one computes the product:

$$n=pq$$

[0021] Then randomly choose the encryption key, e, such that e and (p−1)(q−1) are relatively prime. Finally, one uses the extended Euclidean algorithm to compute the decryption key, d, such that

$$ed=1 \ mod \ (p-1)(q-1))$$

[0022] or, upon solving for the decryption key d,

$$ed=e^{-1} \ mod \ (p-1)(q-1))$$

[0023] From the equations, it is clear that both d and n are relatively prime. The numbers e and n are the public key; the number d is the private key. The two primes, p and q are no longer needed and are discarded immediately—never to be disclosed or revealed.

[0024] Again, referring to Schneier, to encrypt a message, you first divide the message into numerical blocks smaller than n (with binary data, one simply chooses the largest power of 2 less than n). For example, if both p and q are 100-digit primes, then n will have just under 200 digits and each message block, mi, should be just under 200 digits long. The encrypted message, c, will be made up of similarly sized message blocks, c_i, of about the same length. The encryption formula is simply:

$$c_i=m_i^e \bmod n$$

[0025] To decrypt a message, one takes each encrypted block, c_i, and computes:

$$m_i=c_i^d \bmod n$$

[0026] Bloom-Shamir

[0027] There is another prior-art scheme that deals with the problem of splitting a secret into several components so that no one individual or group of individuals can produce the secret unless the required number of components are available. Often called an M-out-of-N scheme, it allows the customer to reduce the risk of malfeasance by requiring that M out of N (where M is one or more but less than N) people all agree to certain acts. One such M-out-of-N implementing algorithm is the Bloom-Shamir algorithm that is defined in "Generalized Linear Threshold Scheme" by S. C. Kothari, (Proceedings of CRYPTO 84). See also: S. C. Kothari, "Generalized Linear Threshold Scheme," in Advances in Cryptology—CRYPTO '84", G. R. Blakley and D. Chaum, eds.; and Lecture Notes in Computer Science volume 196 (1985), pages 231-41.

[0028] Software tools are available for implementing cryptographic schemes into software applications and user-interfaces. One such tool kit is called "BSAFE" and is produced by RSA Security of Bedford, Mass. Information regarding BSAFE and other products, and about public key infrastructure, is available at the RSA web site at http://www.rsasecurity.com/.

[0029] Public Key Cryptographic Standards (PKCS)

[0030] Widely used methods of performing cryptographic operations are described in the Public Key Cryptographic Standards (PKCS), a set of standards for public-key cryptography developed by RSA Laboratories [PKCS]. The present invention makes use of:

[0031] PKCS#1—a mechanism for encrypting and signing data; and

[0032] PKCS#5—password-based cryptography method.

[0033] Authenticode

[0034] The Microsoft Corporation of Redmond, Wash., developed a technology in 1996 that enables users of the Internet's World Wide Web to download binary code (libraries and programs) in a manner that ensures the authenticity of the code. This technology has been dubbed "Authenticode" and is the subject of a white paper published by Microsoft in 1996 entitled "Microsoft Authenticode Technology, Ensuring Accountability and Authenticity for Software Components on the Internet." The document is available via the Internet at: http://msdn.microsoft.com/workshop/security/authcode/authwp.asp and is herein incorporated by reference.

[0035] According to the white paper,

> [0036] ". . . [u]sing Microsoft Authenticode technology, end users can be assured of accountability and authenticity for software components they download over the Internet. Authenticode alerts users before Web sites download executable files to their computers. If code is signed, Authenticode presents the certificate so the user knows that the code hasn't been tampered with and so the user can see the code's publisher and the certificate authority. Based on their experience with and trust in the software publisher, users can decide what code to download on a case-by-case basis."
>
> [0037] "Digital certificates are issued by independent certificate authorities such as VeriSign to commercial and individual software publishers. The certificate authority verifies the identity of each person or company registering, assuring that those who sign their code can be held accountable for what they publish. After successfully completing the verification process, the certificate authority issues the software publishing certificate to the publisher, who then signs its code before shipping an application."
>
> [0038] "Users benefit from this software accountability because they know who published the software and that the code hasn't been tampered with. In the extreme and remote case that software performs unacceptable or malicious activity on their computers, they can also pursue recourse against the publisher. This accountability and potential recourse serve as a strong deterrent to the distribution of harmful code."
>
> [0039] "Developers and Webmasters benefit tremendously from Authenticode as well. By signing their code, developers build a trusted relationship with users, who can learn to confidently download software from that publisher or Web site. Moreover, end users can make educated decisions about what software to download, knowing who published the software and that it hasn't been tampered with." Authenticode white paper, page 1.

[0040] The Operational Paradigms

[0041] The growth of e-commerce requires that end-users be assured that their transactions are private, unmodified, and provable. The cryptographic techniques described above are often used to provide these attributes. In such a transaction, it is important to note the role of the originator of the transaction in exercising independent will to do the transaction. In the workstation paradigm, it is possible to follow the steps of a transaction from the originator's perspective as follows, assuming that the originator is using, for example, a personal computer or terminal:

[0042] The originator decides what is to be done. This is the act of independent will, and will most often by done by a live person. Using the computer, the originator supplies the

necessary information defining the nature of the transaction. This could be something like "Please transfer $100.00 from my checking account to my savings account." How this is done is not really important. The originator instructs the computer to sign and encrypt the data. The encryption step will ensure the privacy of the information as it flows from the computer to its destination (perhaps a bank). The digital signature will provide integrity and dissuade repudiation. The digital signature is evidence that the originator did create the event and that the event actually happened. This is useful in case the recipient of the request wants to prove that the originator requested it rather than some impersonator.

[0043] Signing the data requires that the computer have access to the private keys (cryptographic secrets) of the originator. Encrypting the data requires that the computer have access to the public key of the intended recipient, and the authenticity of that key can be proven provided the computer program has access to a trust root. The computer will ask for a secret that known only to the originator, such as a password, which will unlock the private keys and trust roots, and allow the signing and encryption to go forward. After the data has been signed and encrypted, the computer will erase the secret keys and passwords to reduce the risk of their being used again without obtaining the originator's active consent. It is important to note, in the above sequence of steps, that the originator was personally involved in the process, and only with consent did the digital signing occur.

[0044] Unlike the above workstation situation, servers usually need access to keys all the time. Whereas the originator was present to provide needed passwords, servers are often unattended. Similarly, in the workstation paradigm, a small number of events are occurring concurrently. However, in the server paradigm, large numbers of concurrent events are occurring, each of which may require the use of secret information.

[0045] In the workstation paradigm, the originator is involved in credential renewal, comparable to renewing one's driver's license. In the server paradigm, one cannot suspend business operations while new keys are issued.

[0046] Additionally, the need to protect keys against exposure can be different. In a workstation environment, exposure of keys could cause problems with the originator's resources, but the damage would be confined to this one person, and the cost of that damage contained. On the other hand, in a server, compromise of the keys could jeopardize all the users and their accounts. For example, one is generally willing to spend more effort protecting a bank's resources than one is willing to spend to protect an individual's resources.

[0047] In the past, the problem of the server environment has been addressed by a variety of efforts. Application designers are faced with a dilemma of how to protect these secrets (typically cryptographic keys). Storing them in a text file, or within a program, or even in an independent box, is an open invitation to fraud. Text files can be copied and examined easily by most anyone with access to the computer (in fact, really protecting a file system is difficult). Keys stored in programs can make the program files themselves a valuable target of fraud. Keys stored in independent boxes become vulnerable because it is difficult to control which programs or which agents access the box.

[0048] Furthermore, relying upon firewalls helps protect the secrets against external attack, but leaves unguarded fraud from corruptible employees. Traditional banking practice requires multiple individuals to perform certain tasks, such as opening a vault. To enforce this requirement separate keys are entrusted to separate trusted officers, and the vault is unlocked using both keys.

[0049] The prior art public key infrastructure (PKI) schemes are built upon a "workstation paradigm." The workstation paradigm has an individual user, at a given workstation, that utilizes encryption technology on the workstation to send encrypted messages to another person, or themselves at another workstation. In the workstation paradigm, servers are used only as transport mechanisms. The advent of the worldwide web of the Internet has eroded many of the underlying assumptions of the workstation paradigm. Unfortunately, the prior art PKI schemes have not kept pace. There is, therefore, a need for a crypto-system that allows multiple simultaneous users having multiple sessions while preserving security and integrity of both keys, signatures, access rights, and an apparatus and method to enable automated trust relationships on computer server for multiple applications and multiple users.

SUMMARY OF THE INVENTION

[0050] The present invention provides a paradigm shift from the workstation-centric cryptographic system to a server-centric cryptographic system. In accordance with the present invention, a Key Repository process is configured to validate and record in a database pre-authentication information that identifies those software applications that are authorized to obtain sensitive information including secret cryptographic credentials such as cryptographic keys. The Key Repository process is further configured to authenticate those applications and allow them to obtain the sensitive information from the database.

[0051] The Key Repository process of the present invention addresses the management of trust within an enterprise. The Key Repository process of the present invention does not replace the traditional functions performed by firewalls and sound security policy, it simply augments them. A Key Repository process is initiated with human action, and after the necessary steps of authentication and authorization, the keying material is made available to this process. The Key Repository process is the only program in the computer system that knows the critical secrets. The Key Repository process will supply selected keying material to pre-authorized applications, thus limiting the spread of the secret information, and eliminating the need for human intervention after system startup. The Key Repository process enforces policy decisions in such areas as identifying authorized applications, changes in parameters, and does so by requiring multiple approvals before changes are implemented. In addition, software programs can be pre-authenticated to act as an extension to the Key Repository process.

[0052] The Key Repository process never records sensitive data in the clear on disks, avoiding the problems that could occur if there was any unauthorized access to the disk storage, or to the disk or backup media. Should someone have access to such disk or backup media, uncovering the secrets would be infeasible since the attacker would have to have access to multiple distributed passwords. The memory

and internal data transfer paths are presumed to be secure enough to handle the movement of sensitive data. The Key Repository process also enforces a variety of security policies, such as authenticating operators and owners, controlling the lifetime and quality of generated keys, requiring multiple approvals before changing security parameters, etc.

[0053] Application programs, implementing the customer's business functions, may request copies of keys or other cryptographic secrets. To prevent some rogue or unauthorized programs from obtaining keys, each program entitled to receive keys must be authorized by the key owners. This removes the necessity for programmers to embed keys within a program, to store them in the clear on data files, or to be present to supply passwords when the application program is initiated.

[0054] In most environments, the Key Repository process can be expected to be present and provide the needed services on demand, allowing it to partake in mission-critical business applications. The Key Repository process can thus be expected to survive even in the face of the usual single points of failure that are allowed for by the computer system. This means that the human restart of the Key Repository process is needed only rarely.

[0055] Using commands or directives issued to Key Repository process, the customer's staff interacts with the Key Repository process. Many of the activities are considered security related, in that they involve the extension of trust. For these activities to become effective, the approval of one or more individuals is required. Initially, the system requires just one approved individual, but this number can be changed to any number (the change itself is of course a security-related operation). For example, the customer might want to require that any five out of nine key owners to approve of certain security parameters. These key owners are individuals with a name and password, known to the Key Repository process' database.

[0056] Security related operations include the following types of functions:

[0057] a) Changing the number of approvals required;

[0058] b) Adding or deleting operators or owners;

[0059] c) Pre-authenticating an application program as being allowed to obtain certain cryptographic secrets;

[0060] d) Modifying the cryptographic algorithms in use; and

[0061] e) Pre-authenticating a program to act as an extension of the Key Repository process.

[0062] These features permit the enterprise to manage and control e-commerce applications, while enforcing the security policy that fits the business model. Authorized application programs have access to the cryptographic secrets needed to fulfill the business functions, but no single individual (or small group of individuals) can easily compromise the security of the system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0063] **FIG. 1** is a block diagram of the processes of the present invention;

[0064] **FIG. 2** is a flow chart of the Key Repository process access method of the present invention;

[0065] **FIG. 3** is a flow chart of the initial key creation method of the present invention;

[0066] **FIG. 4** is a block diagram of an alternate embodiment of the present invention;

[0067] **FIG. 5** is a block diagram of an alternate embodiment of the present invention; and

[0068] **FIG. 6** is a flow chart of the method of establishing a cryptographic link between the master keys of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0069] The present invention solves the problems inherent in the prior art by providing an apparatus and method for mimicking the human login process for specific and individual processes on a server-based computer system. Although the present invention may be deployed on a wide variety of computer architectures, in its best mode, the present invention is used on high-availability servers, such as the Non-Stop® Himalaya server systems produced by the Compaq Computer Corporation of Houston, Tex.

[0070] The method and apparatus of the present invention enable end entities to conduct commerce over unprotected networks (such as the Internet) in a secure fashion. In cryptographic parlance, an end entity is a person, router, server, software process, or other entity that uses a digital certificate to identify itself. In the context of the present invention, the definition of "consumer" includes any end entity. However, the definition of "consumer" for the present invention is broader in that it can include both people and organizations (both de facto and de jure). "Consumer" is, interchangeably, also referred to herein as a "client." In this sense, the consumer of the present invention can be an individual (with or without their own digital certificate) sitting at home trying to access their bank accounts. It can also be a business enterprise that has an automated software agent purchasing products based upon some predefined criteria. It will be apparent to those skilled in the art that the consumer of the present invention can be a wide variety of entities (real, legal, and abstract).

[0071] The term "enterprise," in the context of the present invention, has essentially the same definition of "consumer." A separate term is used in order to illustrate more clearly the two sides of a transaction using the present invention. In practice, however, a consumer is typically a person or small business organization. An enterprise can be a business organization of any size. While this is not necessarily always the case, for purposes of the following illustration, a consumer can be thought of as an individual person and an enterprise can be thought of as a business organization even if owned/operated by one person.

[0072] The Processes of the Present Invention

[0073] The basic architecture of the present invention includes several components as shown in **FIG. 1**. The computer system **10** can be composed of one or more computer servers or other computing devices. The only requirement of the server or device is that it be able to run one or **10** more of the processes of the present invention. If

only one server is used, it must be capable of executing all of the processes of the present invention. Otherwise, if multiple servers are used, then the processes may be "farmed out" or instantiated on separate servers that are connected to a common network. In an embodiment of the present invention, it is assumed that the transmissions between the servers of the computer system **10** can be made in a secure manner. The common network mentioned above is not intended to be something like the Internet, unless extra transmission-related security measures (such as SSL (Secure Socket Layer), SSH (Secure Shell) or IPSec (Internet Protocol Security), etc.) are invoked.

[**0074**] The present invention uses cryptographic keys to manage confidential information on a database. Two keys form a set of master keys in the present invention. Each of the two master keys performs a specific function within the cryptographic scheme of the present invention. One of the keys is configured within a Key Repository process to maintain the integrity of critical information on the database. The other master key is used within the Key Repository process to protect the confidential information on the database.

[**0075**] An alternate embodiment of the present invention can utilize one master key in the Key Repository process. This single master key would be used both for integrity of the critical information on the database as well as to protect the confidential information. However, use of a single key may give the user pause to let operators have access to a complete key. Therefore, a single master key may require reformulation of the administrative procedures for the generation and use of the single master key.

[**0076**] According to **FIG. 1**, the Key Repository process **20** is a process that runs on the computer system **10**. The Key Repository process **20** is configured to validate and record in the database **30** pre-authentication information that identifies those software applications **40** that are authorized to obtain secret cryptographic credentials **32** and to authorize those applications **40** to retrieve from the database **30** sensitive data such as cryptographic keys. The Key Repository process **20** makes use of a database **30** to save necessary information. Included on this database **30** are one or more entries defining Operators, and two or more entries defining Owners. The Operator entries are used to retain the value of the Integrity Key **22**. The Integrity Key **22** is configured to ensure the integrity of sensitive information within the database **30**. The Owner entries are used to retain a share (described below) of the Protection Key **24**. The Protection Key **24** is configured to protect sensitive information on the database **30**. In both cases, the entries protect their respective secret by a password-based public-key encryption method described below. Finally, database **30** also stores the enterprise credentials **32** of the enterprise **31** that sponsors the application **40**. In this illustration, the consumer **50** uses the applications **40** to conduct business with the enterprise **31** whose enterprise credentials **32** are retrieved from the database **30**, thus allowing applications **40** (representing the enterprise **31**) and consumer **50** to conduct business. This business transaction can be two-way in that the application **40** can be the business conduit on behalf of either or both the consumer **50** and the enterprise **31**.

[**0077**] Password-Based Public-Key Encryption

[**0078**] When the Operator or Owner is introduced to the system, the process of the present invention first obtains a name and a password from the command interface. Second, the process invents a salt value and a public/private RSA key pair. None of these values are revealed to the individual. The RSA encryption scheme requires the use of two keys, one of which is usually public and is not hidden, the other that is private. For purposes of the present invention, a salt value is a random number whose value is known and saved, but itself has no information encoded in it. A salt value is also sometimes called a nonce.

[**0079**] Third, the Operator's or Owner's password is combined with the salt value to compute a symmetric key and initialization vector, and, using any of a number of symmetric encryption algorithms in cipher block chaining (CBC) mode, the operator's or owner's RSA private key that was invented above, is encrypted. The methodology for this is described by RSA's PKCS #5 (password-based encryption), although the method described by RSA has been extended by allowing the customer to specify which hashing algorithm is used, the hash-iteration count, and the symmetric encryption algorithm. For purposes of this application, a hash (also known as a message digest) is a function that takes input data and produces a short answer (typically 128 or 160 bits in length) with the property that, given the answer, it is unfeasible to construct input data, other than the true data, which will produce the same answer. A hash function is often called a "one-way" function. By repeating a hash function, one increases the amount of time it would take to break the one way function by trial-and-error. Thus, hashes are often repeated thousands of times. In addition, the present invention uses the value of the protection key (one of the master keys) to encrypt the RSA public key. This prevents an undetected modification of the protected secret unless the true RSA public key can be exposed.

[**0080**] The secret, which for Operators is the value of the Integrity Key, and for Owner is their share of the value of the Protection Key, is then encrypted by the RSA public key, using the methodology described by RSA's PKCS#1. The database record for the Owner (or Operator) is then written, and contains:

[**0081**] a) the name of the Operator or Owner;

[**0082**] b) the salt value;

[**0083**] c) the public key of the RSA key pair, encrypted with the protection key;

[**0084**] d) the name of the hashing algorithm used;

[**0085**] e) the number of times the hash value was re-hashed;

[**0086**] f) the name of the symmetric algorithm used;

[**0087**] g) the private key of the RSA key pair (encrypted with password-based encryption); and

[**0088**] h) the secret value encrypted by the RSA key pair.

[**0089**] As implied above, the Protection Key **24** is divided into shares. In an embodiment, the Bloom-Shamir sharing algorithm is used for the division. The number of shares is dictated by the count of Owners known to the system. The order of the algorithm (i.e., the number of shares that will be needed to reconstitute the secret) is dictated by the current value of the Approval Count parameter, which can be any

number between one and one less than the number of Operators known to the computer system **10**.

[**0090**] Although the system of the present invention initially is activated with an Approval Count of one, customers are advised to change the approval count to a higher number in accordance with their own security policy. For example, a banking institution could require that seven out of fifty individuals be required to recreate the bank's Protection Key **24**. The use of seven reduces the fraud-risk, and the availability of fifty candidates increases the chances of locating at least seven. In the present invention, the individuals needed to expose the Integrity Key **22** need not be the same set of individuals needed to re-compute the Protection Key **24**.

[**0091**] The crucial information in the database **30** is protected against modification by an Integrity Key **22** . The confidential data is protected by the Protection Key **24**. When the Key Repository process **20** is restarted, one of the Operators known to the system exposes the Integrity Key **22** by use of the correct identity and password, as described below. The Protection Key **24** is assembled from a set of secrets that are split among multiple individuals, known as Owners, according to the Bloom-Shamir methodology. When the requisite number of Owners have exposed their share of the split Protection Key **24**, using the methodology described below, the Protection Key **24** can be recovered.

[**0092**] Operators and Owners

[**0093**] In the present invention, two distinct classes of system operators are needed. Operators are responsible for the overall computing environment. Any operator can start the Key Repository process, and in so doing, asserts that the computer system is indeed what it claims to be. In alternate embodiments of this invention, this assertion is used to unlock and expose a set of cryptographic credentials with which the Key Repository process can communicate in a trusted and secure fashion with resources external to the platform, allowing that resource to be, but not limited to, the following set of functions:

[**0094**] a) A remotely located owner can perform his functions using a secure link; and

[**0095**] b) A remote extension of the Key Repository process (Remote Agent), or a remote Key Repository process can act on behalf of the local Key Repository process and perform those actions which require access local to the application program.

[**0096**] Initial Key Creation

[**0097**] When the Key Repository process **20** is executed for the first time, that is, without a database **30** from a prior run, the person initiating the process provides the program with the following information:

[**0098**] 1. the name of the database **30**;

[**0099**] 2. the name and password for one operator;

[**0100**] 3. the name and password for one owner; and

[**0101**] 4. the name and password for a second owner.

[**0102**] The Key Repository process **20** defines these individuals in the database **30**, as described above, and creates both a Protection Key **24** and an Integrity Key **22**, encoding these values in the database **30** as described above. The values of both the Protection Key **24** and the Integrity Key **22** are then erased from the computer memory, and can be reconstituted by an Operator in conjunction with one or more of the Owners by supplying their respective identity and password.

[**0103**] The method of creating the keys is illustrated in **FIG. 3**. The method starts with step **300**. Thereafter, the name of the database is provided in step **302**. The name and password for at least one operator is provided in step **304**. The names and passwords of at least two owners are provided in steps **306** and **308**. Next, in step **310**, the Key Repository process creates an Integrity Key. Thereafter, the Key Repository process creates a Protection Key in step **312**. It should be noted that the order of the steps previously discussed is not important except that all of the input information must be provided before all of the keys can be created. For example, after the names and passwords have been entered, either one of the keys can be created. After the keys have been created and recorded on the database using the password-based public-key encryption method defined above, the keys are erased from memory. At this point, the Key Repository process is activated by the Operator, and either (at least one) of the Owners who supply their identity (e.g., their user-name) and their passwords, step **314**. The process then ends in step **316**.

[**0104**] At this point, because the initial passwords may not have been well protected, it is recommended practice, and part of an embodiment of the present invention, to require that each operator and owner modify his/her respective password without allowing other individuals to see the keystrokes, and that additional Operators and Owners be added to the list of legitimate operators/owners, as required by the customer's security policy, and that other security parameters (such as the approval count, the algorithm selections) are adjusted, as required by the customer's security policy. All of the above suggestions are, however, optional, and it is within the scope of alternate embodiments of the present invention to not use the elements of the above-recommended practice.

[**0105**] In an embodiment of the present invention, the value of the Integrity Key **22**, as well as each value of a share of the Protection Key **24**, is stored on the database **30** encrypted using the password-based public-key technique. The Operator or Owner by entering his name allows the Key Repository process **20** to find the relevant record in the database **30**. The password supplied by the Operator or Owner is combined with a salt value that is stored in the database **30**. These values allow the Key Repository process **20** to compute the symmetric encryption key, E_{symkey}, and an initialization vector IV, as defined by the well known RSA PKCS #5 methodology. These values are then used to decrypt the secret using the methodology defined by RSA PKCS #1. For Operators, the PKCS #1 methodology will expose the Integrity Key **22**. For owners, the PKCS #1 methodology will expose their portion of the Protection Key **24**. The RSA key pair alluded to is generated by the Key Repository process **20** at the time that the operator or owner entry is initially defined.

[**0106**] The double encryption password-based public-key encryption technique enables the Key Repository process **20** to change the value of either or both the Integrity Key **22** and the Protection Key **24** once the existing key values are

known. Moreover, the changes to the keys can be done without access to operator or owner passwords. In an embodiment of the present invention, this key change occurs in several situations, including:

[0107] a) whenever an operator or owner is added or deleted;

[0108] b) whenever the definition of the algorithms used in the above process is changed; or

[0109] c) whenever the database must be rewritten in order to accommodate an expansion in the size of the database. Other reasons for changing the key values are institutional regulation (such as government security regulations over banks) and national security issues, which mandate periodic changes in key values.

[0110] In addition to the secrets and other information mentioned above, the database **30** also contains policy values and entity credentials that include the enterprise's **31** credentials **32**. The database **30** also includes the certificates, private keys and trust root. Trust roots (also known as a trust points) are verification certificates known to be authentic, and which can be used to derive the trustworthiness of other certificates using the methodology defined by the Public Key and Attribute Certificate Frameworks ITU X.509, CCIT: Recommendation X.509, ISO/IEC 9594 which is available from the American National Standards Institute (ANSI) 1819 L. Street, NW, Washington, D.C. 20036. Note, the end entity is normally an organization (such as an institution or enterprise). However, alternate embodiments of the present invention include humans in the list of enterprises **32**, such as humans or other groupings or entities that own cryptographic keys to be entrusted in a computer program.

[0111] The enterprise end-entity **31**, whose secrets the Key Repository process **20** is protecting in the form of enterprise credentials **32**, is often an institution or enterprise. These secrets are frequently of significant value, and must not be given to unauthorized application programs. For this reason, the Key Repository process **20** records in the database **30** those applications **40** that are authorized to have access to the enterprise credentials **32**.

[0112] When an application is initially authorized by the key owners (those with portions of the Protection Key **24**), the Key Repository process **20** calculates a checksum (akin to the checksum used with Microsoft's Authenticode) that enables the Key Repository process **20** to detect any future modification in the content of the program binary (executable) file. In the embodiment of the present invention, additional commands are available to the owners that direct the Key Repository process **20** to record in the database **30** authorizations that list the enterprise's **31** name and the name of the application **40** and associated program authentication information for which that enterprise's credentials **32** are authorized. This list is used by the Key Repository process **20** to ensure that the application program **40** is authorized to run and to obtain the enterprise credentials **32** of the specific enterprise **31**.

[0113] Unlike prior art cryptographic schemes where all of the vital keys, or the passwords to unlock those keys, are kept in memory, and where that memory could be recorded on some storage device (perhaps by operating-system functions such as swapping), in an embodiment of the present invention, the clear version of these vital keys and passwords are retained in protected physical memory. In this way, the security of the system is enhanced by making it impractical to recover the keys from non-volatile storage. However, alternate embodiments of the present invention can keep the keys in virtual memory.

[0114] Processing Requests for Enterprise End-Entity Keys

[0115] Alternate embodiments of the present invention are illustrated in **FIGS. 4 and 5**. The architecture of the computer system **10** of **FIG. 4** is similar to that illustrated in **FIG. 1**. However, this alternate embodiment adds an extra interface **26** to the Key Repository process **20**. The local interface **26** is used by applications **40** to communicate with the Key Repository process **20** where all of the processes reside on the same computer system **10** as illustrated in **FIG. 4**.

[0116] The alternate embodiment that is illustrated in **FIG. 5**, however, differs from that in **FIG. 4** in that some of the applications **40** are instantiated on a second computer system **11**. As a result, a different authorization/authentication mechanism is required to process the request for enterprise credentials **32**. The applications **40** interact with the local interface **26** on the local agent **21** which can, in yet another alternate embodiment, act as a local Key Repository process. The local agent **21**, then, via a secure mechanism (such as SSH, SSL, IP tunneling, etc.) interacts with the Key Repository process **20** via the remote interface **28** as shown in **FIG. 5**. In this way, the Key Repository process **20** can interact with multiple remote computer systems and thereby extend the scope of capability of the present invention wherein the scalability of the present invention is limited only by the hardware and bandwidth resources.

[0117] It should be noted, however, that remote computer systems, such as the computer system **11** of **FIG. 5**, must have been pre-authenticated and have established a secure connection. Typically, this involves having some human beings (typically Operators) at both ends of the connection to authenticate the machines (i.e., computer systems **10** and **11**).

[0118] Referring to **FIG. 5, a** typical business transaction starts with a consumer **50** in the form of, for example, some person making use of a workstation to formulate a request. Included in this request would be the information necessary to authenticate the consumer (such as a user-name and password and/or a digital certificate), and to transmit that authentication information to the server on the computer system **11**. A connection is made to the business application **40**, which resides in a server on the computer system **11** that is disjoint from the Key Repository process **20** (that resides on the computer system **10**). The application **40**, determining that it needs the enterprise credentials (keys) **32** of the enterprise entity **31** that the application **40** is representing, sends such a request to the Key Repository process' **20** local agent **21**. From the perspective of the application **40**, the use of the local interface **26** on the local agent **21** is identical to the local interface **26** of the Key Repository process **20**. Thus the local agent **21** can correctly be characterized as a remote Key Repository process. Thus an application **40** of **FIG. 4** would behave identically to an application **40** of **FIG. 5**. The request from the application **40** is received by the local agent **21**. The local agent **21** communicates, using a secure com-

munications medium, with the actual Key Repository process **20**, which resides within the computer system **10**. In this communication, the local agent **21** includes the identification and authentication information of the application process **40**, whereby the Key Repository process **20** will be able to determine with assurance which application is making the request. The communication terminates at the local agent remote agent interface **28** of the Key Repository process **20** as illustrated in **FIG. 5**.

[**0119**] In both cases illustrated in **FIGS. 4 and 5**, the Key Repository process **20** now knows with high certainty: 1) the identity of the application program **40** making the request; and 2) the identity of the enterprise **31** whose secrets (enterprise credentials (keys) **32**) are being requested.

[**0120**] The decision whether to grant or to refuse the request is made based upon the information stored in the Key Repository process' database **30**. In this database **30**, the integrity of information is protected by the Integrity Key **22**, and confidential information (such as private keys) is protected by the Protection Key **24**. Both of these values are known to the Key Repository process **20**, and thus the decision can be then rendered based upon authenticated data.

[**0121**] If the decision is made to grant the access, the enterprise credentials **32** are extracted from the database **30**, decrypted using the Protection Key **24**, re-encrypted, and returned to the requesting application **40** as a response along with a password to decrypt the data. In the example illustrated in **FIG. 5**, the response will be protected during the transit to the originating system **11** using the secure connection between them.

[**0122**] Operation of the Present Invention

[**0123**] Control of Enterprise Credentials and Authentication of Application Programs

[**0124**] The method of the present invention is illustrated in the flow chart of **FIG. 2**. This particular method of the present invention presumes that a Key Repository process has been instantiated and that the needed values are already present in the database. Referring to **FIG. 2**, the process begins at step **200**. An application server is instantiated on the computer system (having the Key Repository process and database) in step **202**. The application server is a process within the computer system which executes all or part of the desired application. There may be one or more instances of this application server process. This process may have been activated by the arrival of some work item from the outside (not shown), or may have been pre-initiated and be waiting for work.

[**0125**] Next, in step **204**, work arrives that is to be performed by the application on behalf of one of the consumers known to the system. The application contacts the Key Repository process in step **206**. Next, in step **208**, the Key Repository process attempts to authenticate the application, i.e., to determine if the application has been tampered with since it was first registered with the Key Repository process. If the application has not been tampered with (and is one of the applications that is allowed access to the Key Repository process) it is granted access to the Key Repository process, and execution continues to step **210**. Otherwise, access to the Key Repository process is denied and execution skips to the end with, optionally, an appropriate error message in step **213** and termination in step **220**. If the application has been authenticated, it next requests the enterprise credentials of the enterprise on whose behalf the application is tasked to act, step **210**. The Key Repository process then checks, in step **212**, whether the requesting application is allowed to have access to the enterprise's credentials. If the Key Repository process determines that access is to be denied, an indication of that result is returned to the requesting application, which, after optionally indicating an error in step **213** and terminates at step **220**. If, however, access is to be approved, execution continues to step **214**, where the Key Repository process builds a credential file of the end entity for use by the application. Thereafter, in step **216**, the Key Repository process transmits (gives) the new credential file, to the application along with a password that enables the application to perform its mission. Thus enabled, the application performs the work on behalf of the consumer (and/or the enterprise) in step **218**. In any case, the execution of this method ends in step **220**.

[**0126**] Enterprise End-Entity Key Rollover

[**0127**] The Key Repository process is entrusted with the safe-keeping of the private keys and trust roots of an enterprise end-entity. The public keys are contained in digital certificates signed by an issuing authority (such as a Certification Authority). There are several situations which can occur that warrant the potential re-issuance of the certificates. These situations include but are not limited to:

[**0128**] a) the approach of the expiration date of the certificate, much as a driver's license is renewed prior to its expiration date;

[**0129**] b) a request by the issuing authority to re-issue the certificate, implying that the certificate owner must periodically check some external database; and

[**0130**] c) a notification from the issuing authority to renew the certificate. Any of these conditions can cause the Key Repository process, which owns the enterprise endentity's certificates, to initiate a set of certificate management functions.

[**0131**] In the workstation model, this is usually performed when the user goes through manual logon, and when the individual's keys are currently not in use. In the server model, however, the keys can be in use at any time, and a "logon" event never really happens.

[**0132**] In an embodiment of the current invention, this issue is addressed directly by the Key Repository process. On a time periodic basis, typically once per day but adjustable by the customer, the Key Repository process will check to see if a certificate re-issuance is called for. While this check is going on, and until it is resolved, one way or another, the old keys remain available to applications. During this check, the Key Repository process may utilize the services of a specialized application that acts as an extension of the Key Repository process, but if so, that application has been duly authenticated and authorized to perform such a function.

[**0133**] If the rollover operation results in new or revised keys, the Key Repository process will store these new values in its database. When that storage operation is completed, subsequent requests from applications will receive the new key values. While the applications are still running, however, they can continue to use the older keys. Such requests

from application programs can be stimulated by notification, timeout, encountering stale keys, or other events.

[0134] Secure Preservation of Intermediate State

[0135] In addition to the above activities, the Key Repository process **20** (of **FIG. 1**) maintains a set of symmetric keys that are supplied specifically to authenticated application programs **40**. These symmetric keys allow the application to save intermediate sensitive data to an application-defined database (not shown), or entrust them to insecure cookies (as described below), such that subsequent activities on behalf of the same piece of work can be performed by other application programs **40**. This permits the applications **40** to be implemented as a set of context-free programs, using this application-defined database or cookie as a safe place to store contextual information. Furthermore, these symmetric keys are periodically reissued to ensure their freshness and to preclude sufficient time for compromise. In an embodiment of the present invention, the Key Repository process **20** maintains a limited history of old key values so that old data in the application-defined database or cookies will be recoverable. In alternate embodiments of the present invention, the database **30** can act as the application-defined database. However, in an embodiment of the present invention, the application-defined database is separate from the database **30**.

[0136] Context-free programs normally run on what are called context-free servers. It is within the scope of the present invention that the computer system **10** of the present invention can be a context-free server running context-free programs. An example of a context-free program is a web server because the underlying protocol for web transactions, hypertext transfer protocol (http), is stateless and thus free of context. To provide contextual transactions between computer software processes, the embodiments of the present invention can be equipped to retain state (context) information, including confidential information or sensitive information (or data), across one or more instantiations of application processes using the symmetric keys maintained by the Key Repository process. The application in this instance is configured to convey the sensitive context information first by encrypting the sensitive information and then passing the encrypted sensitive information to another instance of the application.

[0137] Many transactions involve multiple messages between the submitter and the server. There is often a significant time delay between these messages, especially if the submitter must respond manually, for example, by entering some data at a keyboard. During this delay, however, there is contextual information concerning the transaction that must be saved in order to allow the transaction to continue in an orderly fashion. There are many popular ways to save this information.

[0138] One way to save context information is to keep it in the working memory of the server process, and to implement the system such that this same server process instance processes the next incoming message. Unfortunately, this method is expensive, not scalable and not fault-tolerant. The reason this method is expensive is that significant system resources are otherwise unavailable during the waiting period. These significant extra resources must be added to compensate for the processes that are tied up and therefore this method is also not scalable. Moreover, if the process that retains a state fails (or the process in which that process is running fails) the state data is lost and as a result this method is also not fault-tolerant. Accordingly, most modern designs avoid retaining intermediate state in active processes.

[0139] A second popular way is to send the contextual information back to the client, and require its re-transmission with the next part of the transaction. Although this method is commonly used by web-based systems using "cookies", it is expensive in terms of communications bandwidth. However, because it does not matter which server instance is invoked, the application is context-free. Unfortunately, if the information includes security information such as secrets, the key that decrypts that data must then be shared among all possible instances of servers which might receive the continuation of the request. The problems associated with the distribution and control of such a key raise the issues addressed in this specification.

[0140] A third popular way is to save the contextual information on a database, and to retrieve it when the next part of the transaction takes place. Unlike the well-known cookie method, the database retention method does not increase communications cost, but is still context free.

[0141] Server applications written in the second and third methods can be context-free, scalable and fault-tolerant. Within the scope of the present invention, the contextual information will usually include sensitive data (such as cryptographic keys) whose values must be kept private and unmodified. The present invention facilitates the retention of sensitive context by providing authorized application instances with a set of shared symmetric keys, whereby one instance of the server application can use the keys to protect contextual information and another, possibly different application instance, can recover the contextual information because it has access to the same keys. This contextual information can then be transmitted either through the cookie method or in a local database.

[0142] Increasing the Security of the Integrity Key

[0143] The Integrity Key **22**, being accessible by any operator, is more vulnerable than the Protection Key **24**, which requires knowledge of multiple passwords. By linking them together, additional protection of the integrity key is achieved.

[0144] As noted above, the Integrity Key **22** protects the integrity of the database **30**. The Protection Key **24** protects the confidentiality of sensitive data within the database **30**. In addition, the Key Repository process **20** stores within the database **30** a cryptographic link between the two keys, thus making it impossible to modify one without the other.

[0145] In the present invention, this cryptographic link is constructed as illustrated in **FIG. 6** and as described below.

[0146] The process begins at step **602**. In step **602**, a random number source is used to obtain a salt value. Typically, that salt value is 64 bits in length, although salt values of other lengths (longer and shorter) can be used depending upon the desired level of security. In step **606**, the Protection Key is obtained. Similarly, in step **608**, the Integrity key is obtained. The Integrity Key and the Protection key each consist of the name of the symmetric encryption algorithm, an initialization vector and a key value. In

step **610**, the Protection Key value, the Salt value, and the Integrity Key value are concatenated together. The concatenated value is then used as input to the hashing algorithm in step **612** to produce a Hash value (i.e. Hash (<Protection-key>|<Salt>|<Integrity Key>) produces the Hash value). The Hash value, the Salt value, and the name of the hashing algorithm are then written to the database in step **614** and the process ends in step **616**.

[**0147**] The Integrity Key **22** is revealed by having any operator provide a name and a correct password. Thus, any malicious and sufficiently skilled operator could obtain a copy of the database, use the password to reveal the Integrity Key **22**, modify the database **30**, and rewrite it. However, since the Protection Key is still safe, none of the private information can be modified without detection, and this includes the shares of the protection key in owner entries. When this corrupted database is returned to the running system and any operator (not necessarily the malicious one) activates the system, the integrity checks in the database will succeed, and the Key Repository process **20** will be unable to differentiate this corrupt database from a legitimate one.

[**0148**] Unfortunately for the malicious operator, he did not modify the Protection Key **24**. The Key Repository process **20** will detect that the database **30** is invalid (corrupt) at a later time when the owners identify themselves and the original Protection Key **24** is recovered, and the actual key does not produce a valid answer, or the cryptographic link between the keys is tested.

[**0149**] Safeguarding Policy Values

[**0150**] One ramification of the arrangement and the application of the present invention is that a change to a policy (numbers, values, etc.) requires the approval of those members of the enterprise that build the master keys. In this way, single individuals cannot grant themselves unauthorized access to the computer system **10**.

[**0151**] Thus, the present invention contains centralized repository processes for keys, policy, policy decisions, authentication of application programs **40**, and authorizations to use enterprise credentials **32**. An important security feature of the present invention is the status of Key Repository process **20** as a process. The Key Repository process **20** has a data storage function, in that it stores the Integrity Key **22** and the Protection Key **24** in the working memory of the Key Repository process **20**. To protect the security of the master keys within the Key Repository process **20**, special functionality on the computer system **10** is utilized to prevent the contents of the Key Repository process from being copied to a swap file or page file. If this lock memory functionality is not used, the Integrity Key **22** and/or the Protection Key **24** could be copied onto the swap file and be compromised. An embodiment of the present invention keeps the Key Repository process **20** in non-swappable protected physical memory.

[**0152**] Gateways

[**0153**] Alternate embodiments of the present invention are provided with a gateway **60**. The gateway **60** provides a separate process that mimics the workstation paradigm for communication with the certification authority **70** per the certification authority's protocol. This enables the system of the present invention to make use of existing libraries that implement the workstation models (paradigms) to communicate with their respective certification authority (in search of the certification authority certificate), without requiring the modification of that library to make it work with the Key Repository process, since those libraries will have access to the enterprise credentials **32**. As a result, gateway programs are authorized to the Key Repository process **20** using methods similar to that used to authenticate and authorize application programs **40**.

[**0154**] Summary of Normal Operation Flows

[**0155**] To restate the normal operation of the present invention in terms of the block diagram of **FIG. 1**, an application program **40** attempts to perform some activity on behalf of an enterprise end-entity **31**, and requiring the enterprise credentials **32** on the computer system **10**. The application **40** asks the Key Repository process **30** if the application **40** is allowed to access the enterprise credentials **32** (that are stored within the database **30**). In this sense, the Key Repository process **20** is both a repository and an authenticator. It should be noted that the apparatus and method of the present invention can utilize symmetric as well as the more complex asymmetric key methodologies.

[**0156**] In an embodiment of the present invention, the application **40** asks the Key Repository process **20** for access to an encrypted copy of the enterprise credentials **32**. The Key Repository process **20** either provides the password or refuses to provide the password based upon the authorization setup for the enterprise **31** and the application **40**. A predefined policy will decide whether or not the Key Repository process **20** provides the password. As mentioned before, the policy framework is stored within the database **30**. The enterprise credentials **32**, containing the certificates and trust roots of the enterprise **31**, are protected by the Integrity Key **22** and the Protection Key **24**.

[**0157**] The Integrity Key **22** also protects the policy value that defines the number of Owners needed to change policy values. It also protects the Owner entries needed to recompute the Protection Key **24**, and would detect any tampering with those values.

[**0158**] Parameters and Methods

[**0159**] The following is a detailed illustrative discussion of parameters and methods that can be used to implement an embodiment of the present invention. However, it will be recognized by those skilled in the art that considerable modification of this example is possible without departing from the spirit and scope of the present invention.

[**0160**] The Keys

[**0161**] All cryptographic systems are based on the concept of keys. For software cryptographic schemes, the longer the key (i.e., the more bits that comprise the key), the more secure the system. Sophisticated cryptography systems utilize multiple keys in schemes that require multiple individuals to be involved with the invocation of system. Multiple keys preclude the compromise of the system by a single individual, thereby increasing the security of the information contained within the system.

[**0162**] The following keying material is used:

[**0163**] The Integrity Key

[**0164**] The Integrity Key **22** is a strong symmetric encryption key used to provide integrity for most of the database

30. The method used is a Symmetric Message Authentication Code (MAC) as described by Schneier, and uses any of the symmetric encryption algorithms supported by the Key Repository process **20**. The key is generated by the Key Repository process **20** when the database is created, and is regenerated whenever the database is rewritten. The new value of the key is stored in each operator entry, encrypted with that operator's public key, and then saved in the database.

[**0165**] Whenever an operator logs on as part of the initial activation of the Key Repository process **20**, the operator's password and salt are used to decrypt the private key, which in turn is used to decrypt the Integrity Key **22**, which enables the computer program to ascertain that the database has not been tampered with. If the database is already open, this logon provides the Key Repository process **20** with the ability to update the operator's public/private key pair in case one of the parameters which control this operation has changed.

[**0166**] As each subsystem operator is established and the manual password entered, the Key Repository process **20** generates the salt and RSA keys as described above, and the Integrity Key **22** is encrypted with the RSA private key. The reverse step of logging on is as follows:

[**0167**] a) Use the manually entered subsystem operator's name to find the entry in the database;

[**0168**] b) Use the password just entered, the Salt value, the hash iteration count, and the algorithm specifications recorded in the database, compute the passkey, which consists of a symmetric key and initialization vector; then, erase the password;

[**0169**] c) Using the passkey, decrypt the saved private key; then erase the passkey;

[**0170**] d) Verify that the value just decrypted ends with **8** zero bytes, and then discard those bytes;

[**0171**] e) Use the private key value to decrypt the Integrity Key **22**, and then erase the private key;

[**0172**] f) If the system is not yet in the starting state, this is the Integrity Key **22** value, otherwise, the value just revealed ought to be the same as the current value of the Integrity Key **22**; and

[**0173**] g) Discard the subsystem operator's password, passkey, retaining only the Integrity Key **22**.

[**0174**] The Protection Key

[**0175**] The Protection Key **24** is a strong symmetric encryption key used to provide secrecy for sensitive data in the database **30**. It is never kept on the database **30** but instead is reconstructed by combining information from the requisite number of Protection Key **24** Owners. This key can be changed upon request.

[**0176**] As each owner is introduced to the Key Repository process **20**, the Owner's name and password are used to generate the salt and RSA keys as described above.

[**0177**] At a later time, either at database **30** creation, or when the addition of this owner has been approved, a valid Protection Key **24** value will be available. At this point, the Protection Key **24** value is split into N pieces such that any M of them can be used to reconstruct the value, where N is greater than M, and M is greater than one. The methodology is the Bloom-Shamir Secret Splitting algorithm. According to the algorithm, the secret is divided among a plurality of people. As each owner's secret portion is generated, it is encrypted with that owner's public key and stored in the database **30**. Later, when it's time to reconstruct the secret, the needed number of owner's names and passwords are obtained, and:

[**0178**] a) Use the manually entered owner's name to find the entry in the database;

[**0179**] b) Use the Integrity Key **22** to verify that the database is okay;

[**0180**] c) Use the password, the salt value, and the algorithm description to perform a Password Decryption to recover the portion of the shared secret; and

[**0181**] d) When enough portions have been exposed, use the Bloom-Shamir Secret Splitting algorithm is used to recreate the Protection Key **24**.

[**0182**] The Trust

[**0183**] There are some assumptions about the kind of attacks from which we have no protection:

[**0184**] a) An attacker does not have the protection key **24**, nor the passwords to retrieve all of them from the database (note that if the attacker has all but one of the required owner's passwords, the last one still protects the protection key);

[**0185**] b) The attacker will not use supervisory privileges (e.g., root authority) to rummage through the memory image of the Key Repository process **20** and find the keys; and

[**0186**] c) The attacker will not be able to retrieve the keys from the swap image on the disks.

[**0187**] Note, the Operator entry allowed the program to determine that the database **30** had integrity. However, a malicious operator could have generated his own Integrity Key **22**, and pass-phrase, and thus could have substituted the files.

[**0188**] The multiple application owner entries allowed the program to decrypt the data. However, this malicious operator could have inserted his own entries as application owners, and created his own master key.

[**0189**] When the Protection Key **24** is finally exposed, the Certification Authority's **70** signing key is decrypted and verified. Remember it must be self-signed. However, this malicious operator could have used his own Certification Authority to generate all the keys.

[**0190**] In fact, there is no way the system can differentiate between the "real" database, and a totally fake database that is fully populated. The ultimate protection relies upon dual authentication from the original client program (such as the user at the web browser) and the internal environment, relying upon trusted copies of trust roots. This situation is identical to that encountered when two principals wish to authenticate each other; both must have independentlyauthenticated copies of a Root Certificates (or some intermediate trust point) as the root of the trust relationship. However, should any of the normal operators or owners attempt

to interact with this fake system, they would immediately detect failures, exhibiting themselves as password failures.

[0191] Since the database is protected with both the integrity and privacy checks, no security breach will occur if the database is exposed. However, if the attacker has the passwords of enough owners, all security is moot. It is the responsibility of the customer's practices and procedures to guard against this situation. Prudence therefore dictates that both the passwords and the database should be guarded, making it harder for an attacker to succeed.

[0192] Server Application Programs

[0193] Once the Key Repository process **20** has been initiated, and programs authorized to access it, the customer will initiate execution of these programs when needed. The programs will communicate with the Key Repository process **20** to obtain the secrets.

[0194] This communication is encapsulated inside libraries that are provided with the present invention, and use a protocol that has the functionality such that the name and content of the program file of the sender can be determined in a trusted manner using operating-system primitives. This precludes the conveyance of this protocol over an open insecure transport medium. The libraries communicate with the Key Repository process **20** using such a protocol. As a result, the Key Repository process **20** can authenticate the application program **40**.

[0195] It is envisioned that application authentication will be performed when the application first performs credential acquisition (logon), or to restore context, but once done, need not be done again within the instance of this server.

[0196] To direct this operation, the libraries must be provided with the name of the Key Repository process **20** in a notation appropriate to the host operating system. If the application is performing a logon function, the name of the enterprise on behalf of whom the application is acting, is also available. The entity name used here is the same name used in the Key Repository process **20** to identify the enterprise credentials **32**. How this value is known to the application is application-specific. However, UNIX-like environment variables or command-line parameters are suitable ways to pass the name of the Key Repository process **20**, a method which would enhance portability.

[0197] The Key Repository process **20**, upon sensing the incoming request, and using functions available from the operating system (such as the name under which it was addressed) understands that the request is originating from an application program **40** and is about to use the agreed-upon protocol to request and to obtain the user's credentials. If the Key Repository process **20** cannot identify the requesting program as being one of the authenticated applications, the incoming request is rejected with a security violation error, and the attempt is logged as a potential security breach. If the application program is successfully authenticated, the Key Repository process **20** ascertains whether this application **40** is authorized to work with the requested credentials. If this test fails, the Key Repository process **20** responds to the requesting application program **40** with an error that is conveyed back to the user's application as a password failure, emulating a logon failure. However, if the test succeeds, the Key Repository process **20** builds a file containing the needed credentials (or uses one already built), encrypts the confidential data with an invented password. This password and the location of the file are returned back to the libraries inside or associated with the application program **40** which completes the acquisition of the credentials by decrypting the credential file. The application program **40** is then informed of a successful logon, and work can commence.

[0198] The present invention, therefore, is well adapted to carry out the objects and attain both the ends and the advantages mentioned, as well as other benefits inherent therein. While the present invention has been depicted, described, and is defined by reference to particular embodiments of the invention, such references do not imply a limitation to the invention, and no such limitation is to be inferred. The invention is capable of considerable modification, alternation, alteration, and equivalents in form and/or functions, as will occur to those of ordinary skill in the pertinent arts. The depicted and described embodiments of the invention are exemplary only, and are not exhaustive of the scope of the present invention. Consequently, the present invention is intended to be limited only by the spirit and scope of the appended claims, giving full cognizance to equivalents in all respect.

What is claimed is:

1. A cryptographic system in a computer system, the cryptographic system comprising:

a central server;

a remote server;

a database on the central server responsive to signals from the central server, the database being configured to contain sensitive information;

enterprise credentials stored in the database;

a key repository process on the central server, the key repository process having one or more master keys for managing information in the database, the key repository process further configured to access the enterprise credentials and to authenticate authorizations to access the sensitive information in the database;

an agent on the remote server, the agent acting on behalf of the key repository process on the central server; and

at least one application on the remote server;

wherein the agent authenticates authorizations of specific applications to access resources based upon authorizations held and maintained by the key repository process on the central server.

2. A cryptographic system as in claim 1, wherein the key repository process and the agent communicate with each other, the communication being authenticated by a shared secret, and wherein the shared secret is protected by a level of trust equivalent to that with which the shared secret is protected on the central server by the key repository process.

3. A cryptographic system as in claim 2, wherein the level of trust is defined as the number of individuals required for reconstructing the master key and/or for performing a sensitive operation.

4. A cryptographic system as in claim 1, wherein the agent in the remote server is an independent key repository process with a level of trust equivalent to that of the key repository process in the central server.

5. The cryptographic system of claim 1, wherein at least one master key protects the sensitive information in the database.

6. The cryptographic system of claim 1, wherein at least one master key provides privacy protection to the sensitive information.

7. A method used in a cryptographic system for obtaining sensitive information, comprising:

storing enterprise credentials in a database on a central server, the database being configured to contain sensitive information;

establishing one or more master keys for managing information in the database by a key repository process, the key repository process being configured to access the enterprise credentials;

authenticating, by the key repository process, authorizations to access the sensitive information in the database

establishing communications between the key repository process on the central server and an agent on a remote server, the agent acting on behalf of the key repository process on the central server; and

authenticating, by the agent, authorizations of specific applications on the remote server to access resources based upon authorizations held and maintained by the key repository process on the central server.

8. A method for obtaining cryptographic credentials by an application running on a computer system, comprising:

providing a computer system having at least one server and a cryptographically protected database;

instantiating a key repository process on the computer system, the key repository process being configured with a remote agent interface and/or for interface via a trusted link;

instantiating an application process on the computer system;

conducting, by the application process, a query of the key repository process for sensitive information, the query being conducted via the remote agent interface or the trusted link if the application process and the key repository process are located on different servers; and

providing to the application process, by the key repository process, an encrypted file of the sensitive information, the encrypted file being provided via the remote agent interface or the trusted link if the application process and the key repository process are located on different servers.

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