New Hybrid Cryptosystem for Internet Applications

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Abstract

In this paper we demonstrate a new proposed hybrid cryptosystem, which combines the one-time pad that is theoretically unbreakable cipher, with the most strong (standard) encryption algorithms today’s, the RSA public-key algorithm, and the AES standard secret-key algorithm, to offer unconditionally secured cryptosystem. Public-key cryptosystem can be used to create a digital signature. The analysis of the proposed scheme shows that with a digital signature, we can be sure the sender and the receiver cannot deny the signed object, and we can ensure the message integrity. The existence of such a system would enable instant secure communication between subscribers who have never met or communicated before. A system of this kind greatly simplifies the problem of key distribution. A one-time pad, under the assumption that it has been exchanged between parties’ securely, offers unbreakable cipher! Besides, the proposed scheme facilitates additional level of security strength achieved through the involvement of a four level of key-hierarchy.

Keywords: Cryptography; Hybrid cryptosystem; One-time pad; Internet of things; Cyber security

Introduction and Background

The way to benefit from the advantages of both symmetric and asymmetric cryptosystem has evolved a new approach, the hybrid cryptosystem [1]. The pretty good privacy, PGP, digital envelope cryptosystem is a good example. Threats and vulnerabilities on the communication network and the computing system are monitoring, monitoring modification, masquerading, spoofing and time delay and replay. Network protection services and mechanisms enhance the security of the system and information transfer like confidentiality, authenticity, message integrity, sender nonrepudiation, message unforgeability, access control to system assets during message exchange and availability of the computing system. Cryptography provides basic tools, called primitives, such as encryption, digital signature schemes and hash functions. These primitives can be used with a symmetric-key structure or a public-key structure to achieve our goal. In this paper authors demonstrate the proposed scheme, the exchanged messages format, and the employed four level key-hierarchies.

The one-time pad, OTP, cryptosystem is perfectly secure. The major disadvantage of the OTP cryptosystem is the key distribution between the legal entities. Diffie and Hellman solve the problem of the key distribution with the standard Diffie-Hellman key exchange protocol that works without trusted authority. The hard problem behind the strength of their protocol is the Discrete Logarithm Problem (DLP), which opened the world of the public-key cryptography. The Data encryption standard block cipher algorithm, DES, encrypts a plaintext bit string of length 64 using a bit string key of length 56. The key size is too small for current computational power. The need for the advanced encryption standard block cipher algorithm, AES, remained clear that has a flexible key size of 128, 192 or 256 bit string. The public-key cryptosystem can only exist if both one-way and trapdoor one-way functions exist. In this systems two keys are used one to scramble the message, called public key, and one to unscramble the message, called private key. Encryption and decryption keys come in pairs, so that D(E(m, k), k) = m, where m is the plaintext, the parameter k is the private key, and kept with the key holder saved on smart card or e-Token. The parameter k is the public key and is distributed to the network participants or stored in a public directory.

In a computer network, data are exchanged between parties through a variety of different types of computing systems. Computer networks offer several advantages, such as resource sharing, increased reliability, distributing workloads, expandability. Currently, all commercial applications are tended to be done through the Internet. Even the office network environment is now extending to employee’s home [2]. Generally speaking, any network is subjected to threats and vulnerabilities. Network protection service is a service that enhances the security of the system and information transfer. The service counter the network threats and makes use of one or more protection mechanisms. The protection mechanism is a mechanism that is designed to detect, prevent, or recover from a network threat. The protection mechanisms can support confidentiality, authentication, integrity, nonrepudiation, unforgeability, access control [3] and availability. However, several security problems can be inherent during network access and use. That is why, we are in need to support computer networks with a more powerful and secured cryptosystem [4]. In the proposed hybrid scheme in this paper, which represents an extended version [5] provides confidentiality and authentication that can be used for the Internet sensitive applications and file storage. In the following some algorithms and techniques have been presented.

Truly and cryptographic random bits generators

A number of network security algorithms based on cryptography make use of random numbers, such as the exchanged authentication schemes, session key generation, and generation of keys for the RSA public-key cryptosystem. A key stream generator is defined to be perfect if it is random and unpredictable, or indistinguishable by all polynomial-time statistical tests. The following three criteria are used to validate that a sequence of numbers is random:

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1. Uniform distribution: The frequency of occurrence of each of
the numbers should be approximately the same.
2. Independence: No one value in the sequence can be inferred
from the others.
3. Unpredictability: It means that each number is statistically
independent of other numbers in the sequence.

Electrical noise can be turned into a signal, which can switch a gate
on, and off, one method of generating random bits by using the zero
crossings of this signal to produce pulses, which change the value of
single-digit binary counter. For cryptographic applications, it makes
some sense to take advantage of the encryption logic available to
produce random numbers. Typical examples are the cyclic encryption
approach, suggested, and used to generate session keys from a master
key. The data encryption standard (DES) algorithm output feedback
mode (OFB) can be used for key generation as well as for stream
crpytography. The standard ANSI X9.17 [6] pseudo random number
generator represents one from the strongest CRNGs. PGP hybrid
encryption. The standard ANSI X9.17 [6] pseudo random number
system employs this component.

Hash functions and data integrity

A hash function is a computationally efficient function mapping
strings of arbitrary length to binary strings of some fixed length,
called hash values. If H is a hash function than it is a transformation
that takes input m and returns a fixed-size string, which is called the
hash value h, that is h = H(m) where h represents the “fingerprint” of
a file, or a message. This has been appended to the message at the
sender. The receiver authenticates that message by re-computing
the hash value, and matching it with the received one. To be useful
for message authentication, the hash function H should be one-way and
collision-free. The output length of the hash code should be substantial.
The standard secure hash algorithm (SHA-1) was developed by the
National Institute of Standard and Technology (NIST) organization in
USA [7] that was published in 1994. The algorithm produces a 160-bit
message digest output and more secure against brute-force collision
and inversion attacks [8,9]. A problem is called “easy” if we can find a
polynomial-time algorithm to solve it and “computationally infeasible”
or “hard” if no deterministic or probabilistic polynomial time algorithm
is known to solve it.

The OTP cryptosystem

The OTP, fist described by Gilbert Vernam in 1917. In the OTP
cryptosystem [10], two copies of one set of the TRNG is generated
and distributed over the sender and the receiver. For the strength of
the OTP it should fulfill many properties stated [5].

RSA Public Key Cryptosystem

The RSA cryptosystem, named after its inventors Rivest, Shamir,
and Adleman, is the most widely used public-key cryptosystem. It may
be used to provide both secrecy and digital signatures and its security
is based on the intractability of the integer factorization [11]. RSA
encrypt a message block m ∈ [0, n-1] by computing the exponential c = m^e
mod n where n and e is the key of enciphering transformation and
referred to as modulus and encryption exponent. The m is restored by
the same operation by using different exponent d or the key, referred to
as the decryption exponent, by computing the exponential m = c^d
mod n. The modulus n is the product of two distinct large random primes; p
and q then, n = p. q and

\[ \phi(n) = (p - 1) \cdot (q - 1), \]

where \( \phi(n) \) is the Euler function. Choose d > 1, a large random number, in the interval \([\max(p, q) + 1, n-1]\), such that \( (d, \phi(n)) = 1 \). The two numbers \( (n, e) \) constitutes

the public encryption key, whereas the remaining items \( p, q, \phi(n) \), and
d form the secret trapdoor. The encryption/decryption transformations
are based on Euler’s generalization of Fermat’s theorem, which states that
for every m relatively prime to n, m \( ^{e \cdot d} \mod n = 1 \), which implies that
if e and d satisfy the relation e. d mod \( \phi(n) = 1 \) and the message m \( \in [0, n-1] \) such that gcd (m, n) = 1, then

\[ (m^e \mod n)^d \mod n = m. \]

By symmetry, enciphering and deciphering are commutative and
mutually inverses, thus

\[ (m^e \mod n)^d \mod n = (m^d \mod n)^e \mod n = m^{ed} \mod n = m. \]

RSA Digital Signature

The sender creates a digital signature sig by exponentiation sig
as m^e mod n, where d is the sender private key. She sends m and sig to
the receiver. To verify the signature, the receiver checks that the message m
is recovered m = sig^d mod n, where e is the sender’s public key. In RSA
algorithm the p and q parameters must have certain criteria to achieve
maximum security for the generated keys, hence ensuring the security
of the encryption and decryption processes using these keys.

Calculating the difference between p and q and finding if that
difference is less than a given value does checking for closeness of p and
q. That value is not a constant value but instead changes when p and q
gets larger. The larger the values of p and q the larger that limit must be.
So, the checking is done on the “relative difference” of the two numbers.
The relative difference is the ratio of the value of the difference between
the two numbers, p and q, and the value of the smaller of the two numbers (q). In our proposed system, the relative difference must be larger than 1/128 (0.0078). That is,

\[ \frac{p - q}{q} > \frac{1}{128}, (\delta = p - q, \delta > \frac{1}{128}, \delta > \frac{q}{128}, \log(\delta) > \log(q), (q) - 7. \]

This condition must be satisfied to ensure that the two numbers are
not close together for highly secure parameters p and q.

The Digital Envelope Technique

Although Public-key Cryptosystem [12-14] offer industrial–strong
security, it does not mean that secret-key Cryptosystem [12] has gone-
off. Public-key cryptosystem are slow in comparison to secret-key
cryptosystem, and that is a big concern for anyone who has to send
and receive long messages. The Digital envelopes technique is based on
the combination of the benefits of both the symmetric and the
asymmetric cryptosystem. The strength and the key management of
the asymmetric algorithms and the performance and the speed of the
symmetric algorithms will also be applied in the hybrid systems. Secret
session key of the symmetric algorithm must be used only once, which
is recommended, all over the communication. This technique solves
the key exchange problem, and the performance. The S-MIME and
PGP hybrid cryptosystem are the standard digital envelope technique
[15,16]. A number of known attacks exist against PGP. Many of these
attacks [17,18] are the brute-force attacks, the private key ring and pass
phrase attacks, the public key ring attacks, and the program security.

This paper is organized as follows. Section I introduces general
introduction ad some basic algorithms and techniques that can be
applied for internet applications. Section II introduces the proposed
scheme. Section III discusses the analysis and results of the proposed
scheme. Section IV presents the conclusion and future work.
The Proposed Unconditionally Secure Hybrid Scheme

The Proposed hybrid scheme provides confidentiality and authentication that can be used for the Internet sensitive applications related to the government activities such as the diplomatic and the military activities and file storage. In the proposed scheme the SHA-1 algorithm to calculate the fingerprint of the message has been used. Table 1 contains the terminology that will be applied.

| Terminology       | Meaning                                                                 |
|-------------------|--------------------------------------------------------------------------|
| m, c              | The plaintext and ciphertext messages                                      |
| OTP\(_s\)         | The washed One–time Pad                                                   |
| AES\(^{-1}\)      | AES decryption algorithm                                                 |
| Kid               | The 256–bit AES session key                                               |
| RSA\(^{-1}\)      | RSA decryption algorithm                                                 |
| KRA, KPB          | The private and public keys of the sender A                               |
| KRB, KPA          | The private and public keys of the receiver B                             |
| SHA               | The secure hash algorithm SHA-1                                            |
| Sig               | The signature (message digest encrypted by KRA)                          |
| CK                | The Kid and the Scheme Pointers encrypted by the KPB                      |
| Env               | The resulting digital envelope                                            |
| Digest, Digestg   | The received and generated digest respectively                            |
| + ⊕                | Concatenation and Vector sum modulo two operation                        |

Table 1: The sending cycle.

(a) The sending cycle
1. Washing Process:
   \[ C = OTPe ⊕ MT = OTPe ⊕ [ m + \text{sig} ] \]
   \[ OTPe ⊕ [ m + \text{RSA}^{\text{KRA}} (\text{SHA} [ m ]) ] \]
   \[ \text{Env} = c + CK \]
2. Key exchange Process:
   \[ \text{Kid} = \text{RSA}^{\text{KRA}} [ \text{CK} ] \]
3. Digital Envelope Opening Process:
   \[ \text{MT} = c ⊕ \text{OTPe} = (\text{OTPe} ⊕ (m + \text{sig})) ⊕ \text{OTPe} \]
   \[ m + \text{sig} = m + \text{RSA}^{\text{KRA}} (\text{SHA} [ m ]) \]
   \[ \text{Digest} = \text{SHA} [ m ] \ldots \text{generated by the receiver} \]
   \[ \text{Digestr} = \text{RSA}^{\text{KPA}} [ \text{sig} ] \]
   \[ \text{RSA}^{\text{KRA}} (\text{RSA}^{\text{KRA}} [ \text{SHA} [ m ] ]) = \text{SHA} [ m ] . \]

Then, the two fingerprints, Digest, and the Digestr, are compared for matching to validate the sender and the integration of the received message. Before using OTP to encrypt the message, the OTP string is encrypted through the washing process using AES algorithm with a random 256-bit session key. Each OTP key and session key is used only once for each message. To protect the used session key, it is encrypted with the RSA receiver's public key, and sent together with the encrypted massage.

Results and Analysis of the Proposed Scheme

The strength of AES algorithm or the strength of RSA algorithm does not bound the security of the scheme. The strength of RSA is proved. The RSA attack, the factoring problem, seems to be effective due to the increase in processing speeds in today's computing systems. Increasing the length of the RSA parameters can cover this attack. In our scheme, we implement the RSA algorithm with variable key lengths parameters that can deal with length up to 8192 bits.

The AES algorithm is a 128-bit iterative block cipher with a 256-bit key and fourteen rounds. The security of AES algorithm relies on the use of three incompatible types of arithmetic operations on 32-bit words. One of the principles during the design of AES was to facilitate analysis of its strength against differential cryptanalysis. AES is considered to be immune from differential cryptanalysis [19]. In addition, no linear cryptanalytic attacks on AES have been reported and there is no known algebraic weakness in AES. The strength of AES is also guaranteed due to the increase in processing speeds in today's computing systems. Increasing the length of the RSA parameters can cover this attack. In our scheme, we implement the RSA algorithm with variable key lengths parameters that can deal with length up to 8192 bits.

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If we assume, in the worst case, that the session key has been compromised, then we still have the OTP, which is exchanged, securely between our extranet subscribers. On the other hand, the vector sum modulo two operation employed is fast enough that it does not add any overhead or effect the performance of the scheme. As a conclusion, the OTP provides the security of the scheme if AES or RSA keys have been compromised. On the other hand, if the OTP has been compromised the RSA and AES can guarantee the security of the scheme because we apply the washing process on the used OTP portion before the message encryption process. The scheme employs the SHA-1 to generate the message fingerprint. It provides 160-bit message digest. It is very hard to lie under the Birthday attack.
Conclusion and Future Work

As of today, a lot of applications have been done through the Internet. Electronic mail provides a low cost means of communicating with customers, suppliers, and partners. The Internet greatly simplifies the task of providing information to citizens, clients, suppliers, and partners, or at least those that have computers connected to the Internet. Any use of electronic information publishing reduces the number of requests for information via telephone or mail. Doing research over the Internet generally involves using client software to search for retrieve information from remote servers. Types of client software include File Transfer Protocol (FTP) software that supports logging into remote system, browsing directory structures, and retrieving files. The electronic commerce, the electronic funds transfer, e-Voting election schemes and the future applications related to Internet of Things (IOT) are other important Internet applications. Currently, all commercial applications are tended to be done through the Internet. Even the office network environment is now extending to employee's home.

The Security is the key consideration since a single security incident can wipe-out any cost savings or revenue provided by Internet connectivity. On the other hand encryption algorithms that could need long time to break in the near past, today's it may be broken in shorter time, due to the fast progress in software and hardware technology. That is why we are in need to design new techniques that are considered to be very hard to break.

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