Cryptanalysis and improvement of Petersen–Michels signcryption scheme

W.-H. He and T.-C. Wu

Abstract: Petersen and Michels showed that Zheng’s signcryption schemes lose confidentiality to gain nonrepudiation. They also proposed another signcryption scheme modified from a signature scheme giving message recovery. The authors show that the Petersen–Michels scheme still violates the unforgeability property, and propose an improvement that overcomes the security leak inherent in the scheme. The improvement is as efficient as previous signcryption schemes with respect to both the computational cost and the communication overhead.

1 Introduction

At the Crypto’97 conference, Zheng [1] introduced a new judge (who may be the arbiter of the system) to settle a dispute between the signcrypter and the recipient in an event where the signcrypter denies the fact that he is the sender of the signcrypted text. Basically, a secure signcryption scheme should satisfy the following properties.

Unforgeability: It is computationally infeasible for an adaptive attacker to masquerade as the signcrypter in creating a signcrypted text.

Confidentiality: It is computationally infeasible for an adaptive attacker to find out any secret information from a signcrypted text.

Nonrepudiation: It is computationally feasible for a judge (who may be the arbiter of the system) to settle a dispute between the signcrypter and the recipient in an event where the signcrypter denies the fact that he is the sender of the signcrypted text to the recipient.

Petersen and Michels [3] showed that any secure signcryption scheme achieves the same goals as those provided by the authenticated encryption schemes [4–6]. They also showed that Zheng’s SCS1 and SCS2 schemes lose confidentiality to nonrepudiation, and proposed another signcryption scheme modified from a signature scheme giving message recovery.

In this paper, we will show that the Petersen–Michels scheme still violates the unforgeability property. We also propose an improvement that overcomes the security leak inherent in the Petersen–Michels scheme. Moreover, our improvement is as efficient as previous signcryption schemes with respect to both the computational cost and the communication overhead.

2 Petersen–Michels signcryption scheme and its weakness

The initialisation and key generation stage of the Petersen–Michels scheme works as follows. First of all, the trusted centre (TC) of the system selects two large primes $p$ and $q$, where $q(p-1)$, an element $g$ of order $q$ in $Z_p$, and a one-way hash function $f$ that accepts a variant-length input and produces a fixed-length output. Then, TC publishes $p$, $q$, $g$ and $f$. After that, each user in the system selects a secret key $x \in Z_q$ and computes the corresponding public key $y=g^x \mod p$, where $x$ is kept secret and $y$ certified by TC is made public.

Let $E$ and $D$ be the encryption and the decryption functions, respectively, defined by an available symmetric algorithm, and be previously known to the signcrypter and the recipient. Suppose that a signcrypter $U_a$ wants to secretly send a message $m$ to the recipient $U_b$. First of all, he/she randomly selects an integer $t \in Z_q$, computes $e=f((g^x)^t) \mod p$, and then sends a signcrypted text $(c=E(K, m), r=Ke \mod q, s=t \cdot (r+x) \mod q)$, where $K \in Z_q$ is an encryption key randomly chosen by himself/herself. Upon receiving the signcrypted text $(c, r, s)$ sent from $U_a$, $U_b$ first computes $e=f((g^s \cdot y_a)^r) \mod p$, then obtains $K=r \cdot e^{-1} \mod q$, and finally recovers $m=D(K, c)$.

The main weakness of the Petersen–Michels scheme is that the signature and the encryption can be separated. Two possible forgery attacks against the Petersen–Michels scheme are demonstrated below. Suppose that $U_b$ holds one valid signcrypted text $(c, r, s)$ of a message $m$ generated by $U_a$ and attempts to forge a valid signcrypted text $(c', r', s')$ for another message $m'$ without having $U_a$’s secret key $x_a$. It can be seen that, given $r$ and $s$, $U_b$ knows $e$ and then can easily obtain $K$. Therefore, $U_b$ can easily
forge a valid signcrypted text \((c' = E(K, m'), r' = r, s' = s)\) for any \(m'\) by \(U_a\) without knowing \(x_a\). In an alternative way, \(U_b\) randomly chooses \(r \in Z_q\) and computes \(e' = f((g^r \cdot y_a)^{x_a} \mod p)\) and \(K' = r \cdot (e')^{-1} \mod q\). Again the triple \((c' = E(K', m'), r' = r, s' = s' = \omega \cdot s \mod q)\) is also a valid signcrypted text for any \(m'\) by \(U_o\). Another existential forgery attack also exists in the Petersen–Michels scheme. This existential forgery attack can be done by anyone just by picking random numbers for \(c, r, s\). In such an attack, a recipient can decrypt that signcrypted text and obtains a message which cannot be controlled by the attacker. However, this attack is valid only under the condition that the message does not satisfy a redundancy scheme. From the above analyses, we can conclude that the Petersen–Michels scheme still violates the unforgeability property.

3 Our improvement

In the following, we will present an improvement that can avoid the weaknesses inherent in the Petersen–Michels scheme. The initialisation and key generation stage of our improvement is the same as that in the Petersen–Michels scheme.

Suppose a signcrypter \(U_a\) wants to secretly send a message \(m\) to the recipient \(U_o\). Instead of randomly selecting an encryption key, \(U_a\) first computes the encryption key as \(K = z \parallel f(m, z)\), where \(\parallel\) is the concatenation operator, and computes \(e = f(y_a) \mod p, c\). After that, \(U_a\) constructs \(r\) and \(s\) as does the original Petersen–Michels scheme. Upon receiving the signcrypted text \((c, r, s)\) sent from \(U_a\), \(U_b\) first computes \(e = f((g^r \cdot y_a)^{x_a} \mod p, c)\), then obtains \(K = r \cdot e^{-1} \mod q\), and finally recovers \(m = D(K, c)\). The recovered \(m\) can be further verified by first extracting \(z\) and \(f(m, z)\) from \(K\) and then checking if the extracted \(f(m, z)\) is equivalent to the hash value of the recovered \(m\) and \(z\).

Here, we only reconsider the forgery attacks against our improvement. Regarding how our improvement can gain nonrepudiation without losing confidentiality, the readers can refer to the repudiation settlement procedure presented by Petersen and Michels [3]. In our improvement, the immediate parameter \(e\) can be rewritten as:

\[
e = f((g^r \cdot y_a)^{x_a} \mod p, E(K, m))
= f((g^r \cdot y_a)^{x_a} \mod p, E(\epsilon(f(m, z), m)))
\]

This implies that the attacker cannot separate the signature \((r, s)\) and the encryption \(c = E(K, m)\) due to plotting the forgery attacks. Furthermore, the recovered \(m\) can be verified by only using the obtained encryption key \(K\), without employing a redundancy scheme.

4 Conclusions

We have shown that the signcryption scheme proposed by Petersen and Michels [3] still violates the unforgeability property. We also have proposed a countermeasure in which the forgery attacks can be avoided, without losing confidentiality and nonrepudiation. Our improvement is as efficient as previous signcryption schemes with respect to both the computational cost and the communication overhead.

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