A Novel Multi-factor ID-based Designated Verifier Signature scheme

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Abstract. In a classic digital signature scheme, the global community is capable of verifying a signature. In a designated verifier scheme (DVS), only the designated verifier has this capability. In a classic DVS scheme the signer themselves "designates" the entity that will have the capability of verifying their signature. In a pure identity-based signature scheme a Trusted Authority is introduced, and is responsible for issuing secret signing keys to all participants. In our proposed scheme it is this TA, not the signer, that designates the verifier, and to this end the TA issues the designated verifier with its own secret. Finally we propose a variation that supports non-repudiation, plus a multi-factor signature capability.

1 Introduction

Consider a scenario where a Bank wishes to have the capability of verifying customer signatures on important transactions. It is not important or indeed desired that the general public can verify these signatures - it is sufficient that the Bank is convinced of their validity, and that disputes can be legally resolved if necessary.

In our proposed solution a Distributed Trusted Authority (D-TA) infrastructure will be required which confirms identities and issues shares of the secret keys. The Bank itself would naturally control one component of this infrastructure, but one or more external identity provisioners should be involved as well.

First we design a simple system. Then we add a non-repudiation feature (not normally possible with Identity-Based signature). Finally we show how such a signature method can be made "multi-factor", so for example a customer can sign using a software token and a memorised PIN number. We would suggest that this is a better solution than currently deployed alternatives, which typically require the bank to issue an expensive hardware device to each customer.

2 A Basic Scheme

Our basic scheme is based on an Identity-Based signature suggested by Cha and Cheon [5], shifted from a type-1 pairing to a type-3 pairing context [6]. The security of the Cha and Cheon scheme was established by Bellare et al. [4]

- *Setup.* A Trusted Authority chooses a type-3 pairing friendly elliptic curve and publishes its parameters. The associated bilinear map is $e : \mathbb{G}_1 \times \mathbb{G}_2 \to \mathbb{G}_T$, where all groups are of prime order q. The TA generates a random secret s for use with a particular designated verifier and a fixed public generator $Q \in \mathbb{G}_2$. A hash function $H(.)$ is provided which hashes and maps identity strings to a point in $\mathbb{G}_1$. A second hash function $h(.)$ hashes messages of arbitrary length into a short digest of size less than q.
- *Key Extract - verifier.* The secret key issued to the designated verifier by the TA is the point $sQ \in \mathbb{G}_2$.
- *Key Extract - signer.* For an identity ID_a, the associated ID-based public key is $A = H(ID_a)$. The secret key issued by the TA to ID_a is the point $sA \in \mathbb{G}_1$.
- *Sign.* To sign a message m, ID_a generates a random x, calculates $A = H(ID_a)$ and the signature as $(ID_a, U, V) = (ID_a, xA, -(x + h(m))sA)$
- *Verify.* To verify the signature on m calculate $A = H(ID_a)$ and $g = e(V, Q).e(U + h(m)A, sQ)$, and if $g = 1$ accept the signature, otherwise reject it.

This simple system has a number of short-comings. Clearly the TA is in a position to create a signature on any message, and thus signatures might be repudiated by exploiting a perceived key-escrow issue. One partial solution to this problem is to distribute the TA functionality, and establish a D-TA. For example a pair of D-TAs can generate their own independent secrets s_1 and s_2, and separately issue s_1A and s_2A to a client ID_a, and s_1Q and s_2Q to the designated verifier. Both clients and verifier simply add these components together to form their full secrets.

Nevertheless a conspiracy of D-TAs can still forge signatures. To provide full non-repudiation, we turn to ideas from Certificateless Cryptography [3].

3 A scheme with non-repudiation

The setup and verifier key extraction is as above. We highlight the changes in red.

- *Key Extract - signer.* The client ID_a generates a random z, and calculates a non-ID-based public key $P_a = z^{-1}Q$, and presents the composite identity $ID_a|P_a$ to the trusted authority, which constructs the ID-based public key as $A = H(ID_a|P_a)$, and returns the secret key $sA \in \mathbb{G}_1$. The client then modifies its secret key to be zsA, and deletes z and sA.
- *Sign.* To sign a message m, ID_a generates a random x, calculates $A = H(ID_a|P_a)$ and the signature as $(ID_a, P_a, U, V) = (ID_a, P_a, xA, -(x + h(m))zsA)$
- *Verify.* To verify the signature on m, independently calculate $A = H(ID_a|P_a)$. Next calculate $g = e(V, P_a).e(U + h(m)A, sQ)$. If $g = 1$ accept the signature, otherwise reject it.

2

Certificateless cryptography [3] does not increase the number of secrets to be protected compared with pure Identity-Based cryptography, but it does introduce a new individualised public key P_a. It is assumed that the TA (or equivalently at least one component of a D-TA) will not get involved in an attack involving replacement of these public keys. The authors of [3] argue that this is essentially the same level of trust we have in a PKI Certificate Authority (CA) not to issue false certificates. Hence their schemes are "certificateless", as public keys gain no extra security from being embedded into a certificate. For digital signatures to have the non-repudiation property, an assumption of this kind is regarded as acceptable, and does not invalidate the legality of PKI signatures. Therefore here we assume that at least one of our independent D-TAs has the same level of integrity as a CA.

4   A multi-factor variation

Multi-factor methods of signature are often required by organisations like Banks, and normally require that customers be provisioned with an expensive hardware token. Here we suggest a cheaper software-only solution.

Consider the possibility of splitting a private key used for digital signature into two parts, say a PIN number and a software token. Both components would need to be recombined in order to form a signature. In a normal digital signature scheme clearly this will not work – an attacker who captures the software token simply has to try every possible PIN number until the private key formed by combining token and PIN matches the user's public verification key.

But in our ID-based designated verifier scheme, the single verification key is in fact now a secret known only to the designated verifier. So a software-only 2-factor signature becomes a possibility.

Consider the scenario where an attacker has access to the token and a valid signature. Is this sufficient to find the PIN via an off-line attack? Consider again our basic scheme. Now choose a PIN number α and break the secret into the token $sA - \alpha A$ and the PIN derived component αA.

An attacker who has access to $sA - \alpha A$ and signature components xA and xsA, can try adding guesses of αA to the token, hoping to detect the triplet sA, xA and xsA. But this is the Decisional Diffie-Hellman problem in $\mathbb{G}_1$. It is the XDH assumption [8] that this is still a hard problem, despite the computability of a pairing.

The same idea can be easily extended to our scheme that supports non-repudiation, with the client secret split into the token $zsA - \alpha A$ and the PIN derived component αA. However we observe that this idea will not work with other Identity-Based signature schemes. For example if applied to the scheme due to Hess [7] considered in [3] the PIN can be discovered via an off-line dictionary attack.

The extension of the idea from 2-factor to multi-factor is straightforward.

5 Discussion

A conspiracy of D-TAs can re-create sQ, and therefore can verify signatures. As a consequence, such a conspiracy that gains access to client tokens can calculate the associated PINs. We do not believe that this constitutes a realistic attack, requiring as it does the subversion of all of the D-TAs and breaches of individual client security.

While a conspiracy of D-TAs can forge individual signatures, the security risk is equivalent to that posed by a corrupt Certificate Authority in a PKI signature context. Recall that in this situation the existence of a pair of digital signatures on the same message associated with the same identity, but with different public keys, suffices to expose such a conspiracy.

Revocation can be supported either as described in [3], or using the concept of "time permits", which are publicly issued by the D-TAs on, for example, a daily basis. We omit the details.

6 Application

It has been assumed that as part of the solution to the challenge of secure multi-factor authentication, some kind of hardware vault like a Trusted Platform Module (TPM) is required on the client side. Typical solutions such as that proposed by the FIDO alliance [1] require the protection of a PKI-like signing key on the client device, which is used to sign a random challenge issued by the server every time the client wishes to authenticate. Ideally for an optimal user experience this signing key should be activated from the hardware vault by the entry of a low entropy secret like a PIN number, or a biometric which matches a template stored inside the vault. We should point out that this process is two-step rather than two-factor. An attacker who can gain access to the TPM, either by successful hacking, or by way of a manufacturer's back-door, can gain immediate access to the secret, with no need of a PIN or a biometric. As a bonus they might capture the biometric template as well. It would appear not to be possible to conveniently implement such functionality entirely in software on the client side. As is well known the cryptographic protection of a PKI private key in software requires the use of a very user-unfriendly high-entropy pass-phrase, a process made famous by PGP [2].

Our proposed solution is genuinely two-factor/multi-factor. Furthermore a software only implementation on the client side is now perfectly feasible, which reduces the cost dramatically and removes the need to trust a hardware manufacturer. For a two-factor solution the token is stored unencrypted on the device, and the PIN is memorised by its owner. This is at the cost to the server of protecting a single secret for use in signature verification.

As a full featured non-repudiable signature scheme the method would we suggest have application beyond simple authentication, in contexts where a multi-factor signature capability were desirable, as in our original banking scenario.

References

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