Short Paper: Practically Unbounded One-Way Chains for Authentication with Backward Secrecy*

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Abstract

One-way hash chains have been the preferred choice (over symmetric and asymmetric key cryptography) in security setups where efficiency mattered; despite the ephemeral confidentiality and authentication they assure. They only support forward secrecy and have limitations over the chain size (bounded). In this paper, we show how the use of chameleon functions leads to the generation of practically unbounded one-way chains with constant memory storage requirement, providing forward, and backward secrecy as well. Such a cryptographic tool appears to be a great enabler for a variety of applications that could not be efficiently realized earlier. From our experiments we observed that this new kind of one-way chain formation adds a slight computational burden, which is justifiable by the unique advantages provided under our construction. The basic unit of our construction, chameleon function, can be elegantly used to design trees or even simpler star-like constructs.

1 Introduction

Entity authentication is one of the core primitives that are required to build dependable and secure systems [5]. Several cryptographic protocols have been proposed (e.g. [8, 9, 7]) to reach this goal. These protocols use cryptographic primitives based on a symmetric key crypto-system or an asymmetric key crypto-system. The appropriateness of a cryptographic protocol for an application depends on the computational costs it incurs to the application. Generally, entity authentication is achieved using asymmetric cryptography and data confidentiality by computationally less expensive symmetric cryptography. But, to realize such

a mechanism, an underlying security framework is required, called PKI (Public Key Infrastructure). Integration of such a framework with computation-constrained environment or in dynamically changing setups is not practical due to the costs and complexity of the framework.

A widely accepted approach is the use of one-way hash chains [8] (alternatively referred as Lamport chain, in this paper), that provides verifiable data authentication in an efficient way. Much recent work [9], even tries to achieve the characteristics provided by asymmetric cryptography with the help of one-way hash chains and time synchronization between the communicating principals, where ephemeral data confidentiality is provided and backward secrecy is not guaranteed. Though these approaches try to address a particular domain of applications, the philosophy can be extended to much complex scenarios (e.g. group membership, secure multi-cast communication, key renewal etc.), in distributed environment. The issue of key renewal has special significance because of cryptanalytic reasons and hence, for each key renewal the authenticity of the received key must be assured. Lamport chains achieve these objectives efficiently, but with a few limitations: limited chain length and no backward secrecy. Our construction (named “chameleon hash”, based on chameleon functions [7, 2, 3, 10]) has done away with these limitations. In comparison with the one-way chain based schemes [6], our solution:

1. allows to generate practically un-bounded one-way chain, whose length is only limited by the finite-ness of the field over which the values are generated,
2. has both storage and computation constant requirement,
3. provides both forward and backward secrecy of communication, and
4. does not require generation of the complete chain before starting its use, since generation and usage of the chain proceed in same direction, where the generation process is at least one step ahead of the later.

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Figure 1. Generation and Spending Sequences in SHA-1 and Chameleon Chains

2 Background and Overview

A brief overview of chameleon functions [7, 1, 3, 2] and their properties are given below. To begin with, let us assume that a principal chooses an asymmetric key-pair, where HK_R denotes the public-key and CK_R denotes its corresponding private-key (also called trap-door). Each chameleon hash function is associated with a unique public-key. Let $CH_R(.,.)$ represent the chameleon hash function derived from public-key HK_R . Given a message m_i and a random seed r_j , the $CH_R(m_i, r_j)$ function generates a hash value satisfying the following two properties:

- **Collision resistance:** There is no efficient algorithm that on input the public key HK_R can find pairs m_i, r_i and m_z, r_z where $m_i \neq m_z$, such that $CH_R(m_i, r_i) = CH_R(m_z, r_z)$, except with negligible probability.
- **Trapdoor Collision:** There is an efficient algorithm that on input the secret key CK_R , and any pair m_i, r_i , and any additional message m_z , finds a value r_z such that $CH_R(m_i, r_i) = CH_R(m_z, r_z)$. Therefore,
 1. the knowledge of public key HK_R allows a user to derive the corresponding chameleon hash function,
 2. only the owner of HK_R 's corresponding secret key, CK_R , (also called *trapdoor*) can efficiently find a collision for any given output;
 3. for others, the function $CH_R(.,.)$ offers strong collision-resistance, i.e., it should be computationally infeasible to find two inputs with the same image under this function.

3 Construction of Chameleon Chain

Figure 1 shows how the construction of a SHA-1 based one-way chain differs from chameleon based one. Given a random string m_0 and a seed r_0 , the server computes

k_0 using CH_R . k_0 (the first session-key) is distributed via a secure channel. On the next re-keying the server generates two random values m_1 and r_1 , and computes $k_1 = CH_R(m_1, r_1)$. Further, leveraging the trapdoor collision property, the server efficiently finds a seed s_1 such that $CH_R(k_1, s_1) = CH_R(m_0, r_0) = k_0$. Once the client receives k_1 , it can check the authenticity of k_1 by performing $CH_R(k_1, s_1) = k_0$ check. As need arises, the server can repeat these steps to generate a chain of verifiable keys and use them in the same sequence of their generation. The corresponding steps performed by both parties for generation and verification of session keys are enumerated below;

• Sender/Server :

1. randomly chooses m_{i+1} and r_{i+1} , and creates new key $k_{i+1} = CH_R(m_{i+1}, r_{i+1})$,
2. chooses s_{i+1} such that;
 $k_i = CH_R(m_i, r_i) = CH_R(k_{i+1}, s_{i+1})$, and
3. sends the message $p = E_{k_i}(k_{i+1}, s_{i+1})$ to the user.

• Receiver/Client:

1. receives the message packet p ,
2. decrypts the packet $p = E_{k_i}^{-1}(k_{i+1}, s_{i+1})$ using the old key k_i , and
3. authenticates k_{i+1} by checking if
 $k_i = CH_R(k_{i+1}, s_{i+1})$, otherwise discards k_{i+1} .

Key generation efficiency: Our construction achieves key authenticity in (*memory*computation*) complexity $O(1)$ since it requires: 1) on the server side: a) to store the values of the current key k_i , the next generated key k_{i+1} , the public key HK_R and the secret key CK_R ; b) to build the next session key k_{i+1} performing the chameleon hash $k_{i+1} = CH_R(m_{i+1}, r_{i+1})$ that requires $O(\max\{|m_{i+1}|, |r_{i+1}|\})$ modular exponentiations, to find out a chameleon collision $k_i = CH_R(m_i, r_i) = CH_R(k_{i+1}, s_{i+1})$ that requires $O(\max\{|m_i|, |r_i|\})$ modular exponentiations as well, 2) on the client side: a) to store the values of the public key HK_R , the current key k_i , and the next generated key k_{i+1} sent by the server; b) the chameleon verification $k_i = CH_R(k_{i+1}, s_{i+1})$, that requires $O(\max\{|k_{i+1}|, |s_{i+1}|\})$ modular exponentiations too. Note that $O(\max\{|k_{i+1}|, |s_{i+1}|\})$ is the computational complexity of the schemes proposed in [7, 10].

Use of SHA-1 based one-way hash chains as a tool for improving the efficiency of a variety of practical and valuable security applications is well rooted. However, knowing k_n and given that the current value in the chain is k_i , the cost for computing the value k_{i+1} in the hash chain, is a topic that has largely been ignored for long chains. This task may account for a quite noticeable portion of the total computational effort of the protocol. The technique often employed

is to compute each hash value in the chain (*on-the-fly*) by iterative applications of the hash function starting from an initial seed. However, such a method has a computational complexity of $O(n - i)$ to generate key k_i . Another possible method, in which all values are pre-computed and stored, substantially reduces the *on-the-fly* computational cost, but has a storage complexity of $O(n)$. All straightforward combinations of these two techniques can be shown to have a (*memory * computation*) complexity of $O(n)$, which can be a substantial computational burden for many resource-constrained devices, such as wireless sensor networks or hand-held devices.

4 Advantages of Chameleon Chains

The ability of the owner of the trap-door to efficiently find collisions gives our construction the following prominent properties.

Practically unbounded one-way chain - Unlike Lamport's one-way chain, our scheme provides a one-way hash chain whose length is restricted by the finiteness of the field the chain is built upon. One-way chains using chameleon functions are always generated and used in same direction (i.e. the generator of the chain is at least one step ahead than the last revealed value), whereas in Lamport's one-way chain the generation and usage proceed in opposite directions (thus limiting the length of the chain).

Backward Secrecy - Knowing a value of any unit from the SHA-1 one-way chain, lets one derive all the values between that point up to the *anchor* of the chain. This eventually leads to the exposure of all previous communications secured using the hash values of such a chain. Whereas, in our construction, one can derive only the previous value in the chain; not beyond that. This is an important requirement while using one-way chains for managing group memberships (for example). A newly joined/enabled member should not get undue privileges, other than the assigned ones, when the membership action is performed.

Constant memory storage requirement - In one-way chains derived using SHA-1 hash function, the applications follow a trade-off between storage of the actual chain values and/or re-computation of the values. Such a constraint is absent in chameleon chains since it is not necessary to compute the complete chain in advance.

Time synchronization requirement - The applications (e.g. multi-cast) that use Lamport chains need to loosely time-synchronize the communicating ends to establish authenticity of the content distributed. Our scheme does away with this requirement [4].

5 Conclusions

In this paper, we have derived an analogy between Lamport's one-way chain and one-way chains based on chameleon functions. Our construction has the following advantages over the former: i) practically unbounded length, ii) backward secrecy, iii) constant memory storage and computation requirement, and iv) no time synchronization requirement. These properties, which are otherwise not realizable, come at an extra computational cost [4].

Finally, note that in this paper we have exposed chaining just as one of the possible construct that we could implement. Chameleon hash functions can be used just as easily to construct trees or even simpler star-like constructs which would eliminate the need for the verifier to have all intermediate values [4]. Chaining is only important if causality of signatures is needed.

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