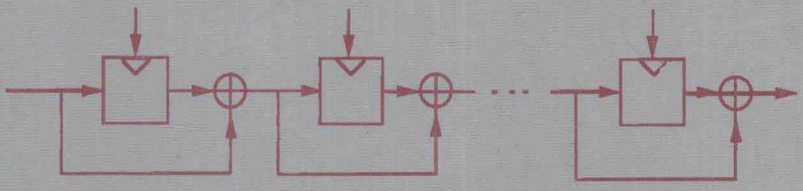
Lecture Notes in Computer Science 756

Josef Pieprzyk Babak Sadeghiyan

Design of Hashing Algorithms



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Preface

Historically, computer security is related to both cryptography and access control in operating systems. Cryptography, although mostly applied in the military and diplomacy, was used to protect communication channels and storage facilities (especially the backups). In the seventies there was a breakthrough in cryptography - the invention of public-key cryptography. It started in 1976 when Diffie and Hellman formulated their public-key distribution system and formally defined public-key cryptosystems. Two years later two practical implementations of public-key cryptosystems were published. One was designed by Rivest, Shamir, and Adleman (called the RSA system); the authors based the system on the two "difficult" numerical problems: discrete logarithm and factorization. The other invented by Merkle and Hellman was based on the knapsack problem, which is even "harder" than these used in the RSA system. Since that time cryptography, traditionally seen as the theory of encryption algorithms, has extended its scope enormously. Now it comprises many new areas, namely authentication, digital signature, hashing, secret sharing, design and verification of cryptographic protocols, zero knowledge protocols, quantum cryptography, etc.

This work presents recent developments in secure hashing algorithm design. The main part of the work was written when the authors were with the Department of Computer Science, University of New South Wales, Australian Defence Force Academy, and Babak Sadeghiyan was a PhD student working with Josef Pieprzyk as his supervisor.

Hashing is a process of creating a short digest (i.e. 64 bits) for a message of arbitrary length, for example 20 Mbytes. Hashing algorithms were first used for searching records in databases. These algorithms are designed to create a uniform distribution of collisions (two messages collide if their digests

are the same). In cryptographic applications, hashing algorithms should be "collision-free", i.e. finding two different messages hashed to the same digest should be computationally intractable. Hashing algorithms are central for digital signature applications and are used for authentication without secrecy.

There have been many proposals for secure hash algorithms, and some of them have been in use for a while. However, many of them have proved insecure. One of the major reasons for this is the progress in technology. The failed effort of many researchers suggests that we should work on some guidelines or principles for the design of hash functions. This work presents some principles for the design of secure hash algorithms. Hash algorithms are classified based on whether they apply a block cipher as the underlying one-way function or not.

For a block-cipher-based hash scheme, if the underlying block cipher is secure against chosen plaintext/ciphertext attack, the hash scheme is secure against meet-in-the-middle attack. We develop structures, based on DES-like permutations and assuming the existence of pseudorandom function generators, which can be adopted both for the structure of block-cipher-based hash schemes and for the underlying block ciphers to be used in such schemes.

Non-block-cipher-based hash functions include a spectrum of many different proposals based on one-way functions from different branches of mathematics. So, in the book, generalized schemes for the construction of hash functions are developed, assuming the existence of a one-way permutation. The generalized constructions are improvements upon the Zheng, Matsumoto and Imai's hashing scheme, based on the duality between pseudorandom bit generators and hash functions, but they incorporate strong one-way permutations. It is shown that we can build such strong permutations with a three-layer construction, in a theoretical approach. Two schemes for the construction of families of strong one-way permutations are also proposed.

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September 1993

Josef Pieprzyk

Babak Sadeghiyan

List of Symbols

C	Ciphertext
M	Message or a plaintext
K	Key
Σ	Alphabet
$\sum$	Summation
$\subset$	Subset
$\rightarrow$	Mapping
$\circ$	Composition of functions
$\in$	Set membership
$\equiv$	Congruence
!	Factorial
|	Such that (set notation)
$\oplus$	Exclusive-or (of Booleans)
$\vee$	Or (of Booleans)
$\wedge$	And (of Booleans)
$\|\|$	Concatenation
$O(f)$	Big-Oh of the function f
$\cup$	Union
$\lceil x \rceil$	Smallest integer greater than x
$\lfloor x \rfloor$	Greatest integer smaller than x
N	The set of natural numbers
Z_n	The set of integers modulo n
$\mid x \mid$	Absolute value of the number x
$\#S$	Number of elements in the set S
$\log_n$	Logarithm to the base n

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Contents

Chapter 1

Introduction

1.1 Background and Aims

1.1.1 Introductory Comments

The development of telecommunication and computer technologies have brought us into an era in which inexpensive contact between people or computers on opposite sides of the world is commonplace. The existing services such as electronic mail, electronic funds transfer, and home banking have already changed our way of life. Electronic mail systems significantly reduce our reliance on paper as the major medium for exchange of information, by providing rapid and economic ways for the distribution of data. It is clear that, with the widespread implementation and use of such services, senders and receivers of sensitive or valuable information will require secure means for validating and authenticating the electronic messages they exchange. The least that may be expected of these services is that they should offer the same security level as that of the conventional mechanisms. In the mail service, conventional paper mail has its own envelope, which protects the secrecy of its contents, it is also signed which assures the recipient of its origin. Similar properties should have the electronic mail service.

On the other hand, the increased use of satellite, microwave, cellular mobile and other forms of radio communication allow the illicit interception of communications. Moreover, the widespread use of computers provides

the interceptors with computer data, which can easily be edited to sort the valuable information. Figure 1.1 schematically shows such a scenario.

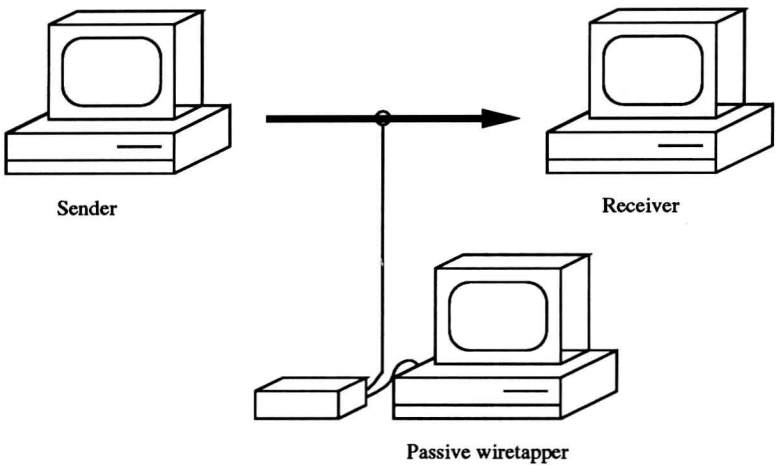

Figure 1.1: Passive Eavesdropping over Communication Networks

While eavesdropping on radio communications is a passive act, an active wiretapper can inject fraudulent messages in other types of communication links such as telephone networks. Figure 1.2 illustrates a possible active wiretapping scenario.

1.1.2 Discussion of Public-key and Private-key Cryptography

Cryptography is the study of mathematical systems for solving two kinds of security problems: privacy and authentication [Diffie and Hellman, 1976]. A privacy system prevents the extraction of information by unauthorized parties from messages transmitted over a public channel, thus assuring the sender of the message it will be read only by the intended recipient. An authentication system prevents the unauthorized injection of messages into a public channel, assuring the receiver of a message of its legitimacy. The authentication problem can be divided into *message authentication*, where the problem is assuring the receiver that the text has not changed since it left the sender, and *user authentication*, where the problem is verifying that