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Updated Security Considerations for the MD5 Message-Digest Algorithm  
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## Abstract

This document updates the security considerations for the MD5 message digest algorithm.

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## 1. Introduction

MD5 [[MD5](#)] is a message digest algorithm that takes as input a message of arbitrary length and produces as output a 128-bit "fingerprint" or "message digest" of the input. The published attacks against MD5 show and that it is not prudent to use MD5 when collision resistance is required. This document replaces the security considerations in [RFC 1321](#) [[MD5](#)].

[HASH-Attack] summarizes the use of hashes in many protocols and discusses how attacks against a message digest algorithm's one-way and collision-free properties affect and do not affect Internet protocols.

## 2. Security Considerations

MD5 was published in 1992 as an Informational RFC. Since that time, MD5 has been studied extensively. What follows are recent attacks against MD5's collisions, pre-image, and second pre-image resistance. Additionally, attacks against MD5 used in message authentication with a shared secret (i.e., HMAC-MD5) are discussed.

Some may find the guidance for key lengths and algorithm strengths in [[SP800-57](#)] and [[SP800-131](#)] useful.

### 2.1. Collision Resistance

The first paper that demonstrates actual collisions of MD5 was published in 2004 [[MD5-Analysis1](#)]. The detailed attack techniques for MD5 were published at EUROCRYPT 2005 [[MD5-Analysis2](#)]. Since then, a lot of research results have been published to improve collision attacks on MD5. The attacks presented in [[MD5-Analysis3](#)] can find MD5 collision in about one minute on a standard notebook PC (Intel Pentium, 1.6 GHz.). In [[MD5-Analysis4](#)], the collision attack on MD5 was successfully applied to X.509 certificates.

Notice that the collision attack on MD5 can also be applied to password based challenge-and-response authentication protocols such as APOP protocol used in post office authentication as presented in [\[MD5-Analysis5\]](#).

In fact, more delicate attacks on MD5 to improve the speed of finding collisions have published recently. However, the aforementioned results have provided sufficient reason to eliminate MD5 usage in applications where collision resistance is required such as digital signatures.

## [2.2](#). Pre-image and Second Pre-image Resistance

Even though the best result can find a pre-image attack of MD5 faster than exhaustive search as presented in [\[MD5-Analysis6\]](#), the complexity  $2^{123.4}$  is still pretty high.

## [2.3](#). HMAC

The cryptanalysis of HMAC-MD5 usually conducted together with NMAC (Nested MAC) since they are closely related. NMAC uses two independent keys  $K_1$  and  $K_2$  such that  $NMAC(K_1, K_2, M) = H(K_1, H(K_2, M))$ , where  $K_1$  and  $K_2$  are used as secret IVs for hash functions  $H(IV, M)$ . If we re-write HMAC equation using two secret IVs such that  $IV_2 = H(K \text{ Xor } \text{ipad})$  and  $IV_1 = H(K \text{ Xor } \text{opad})$ , then  $HMAC(K, M) = NMAC(IV_1, IV_2, M)$ . Here it is very important to notice that  $IV_1$  and  $IV_2$  are not independently selected.

The first analysis was explored on NMAC-MD5 using related keys in [\[HMAC-Analysis1\]](#). The partial key recovery attack cannot be extended to HMAC-MD5, since for HMAC, recovering partial secret IVs can hardly lead to recovering (partial) key  $K$ . Another paper presented at Crypto 2007 [\[HMAC-Analysis2\]](#) extended results of [\[HMAC-Analysis1\]](#) to a full key recovery attack on NMAC-MD5. Since it also uses related key attack, it does not seem applicable to HMAC-MD5.

A EUROCRYPT 2009 paper presented a distinguishing attack on HMAC-MD5 [\[HMAC-Analysis3\]](#) without using related keys. It can distinguish an instantiation of HMAC with MD5 from an instantiation with a random function with  $2^{97}$  queries with probability 0.87. This is called distinguishing-H. Using the distinguishing attack, it can recover some bits of the intermediate status of the second block. However, as it is pointed in [\[HMAC-Analysis3\]](#), it cannot be used to recover the

(partial) inner key  $H(K \text{ Xor } \textit{ipad})$ . It is not obvious how the attack can be used to form a forgery attack either.

The attacks on HMAC-MD5 do not seem to indicate a practical vulnerability when used as a message authentication code. Considering that the distinguishing-H attack is different from distinguishing-R attack, which distinguishes an HMAC from a random function, the practical impact on HMAC usage as a PRF such as in a key derivation function is not well understood.

Therefore, it may not be urgent to remove HMAC-MD5 from the existing protocols. However, since MD5 must not be used for digital signatures, for a new protocol design, a ciphersuite with HMAC-MD5 should not be included.

### [3.](#) IANA Considerations

None.

### [4.](#) Normative References

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