LAB Mode for Iterated Hash Functions

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Abstract.In this paper,we proposed a efficient and laconic mode for iterative hash functions and tried to fix the flaws of the Merkle-Damgaard construction completely and certainly tried to prevent varieties of those generic attacks ,such as Multicollisions Attack,Second Preimage Attack and Herding Attack.The structure of this new mode is different from HAIFA or any other proposal,it contains a new method "Locking Abutting Blocks"(LAB)with checksum ,it makes a large size of connotative chaining value without requirements of intricate computing and large memory and it allows for an online computation in one pass with a fixed memory independently .It's also easy to avoid the generic attacks (presented by Praveen Gauravaram and John Kelsey) which apply on the hash functions with linear-XOR/additive checksum.

keywords: hash function ,iterating ,abutting blocks,effectual chaining variable, checksum blocks

1 Introduction:

Most of the compression functions applications are iterated and the Merkle-Damgaard construction[**?**] is the most widely used transformation of a secure compression function $C : \{0,1\}^n \times \{0,1\}^m \rightarrow \{0,1\}^n$ into a cryptographic hash function $h_c(\cdot)$. (where,n denotes the size of the chaining value,and m denotes the block size for the compression function .)

The iterating hash functions of M-D construction try to maintain the following three properties of the cryptographic secure compression functions :

1.**pre-image resistance:**For any given code h,it is computationally infeasible to find x such that $h(x) = h$.

2. **second pre-image resistance:**For any given block x,it is computationally infeasible to find $y \neq x$ with $h(y) = h(x)$.

3. **collision resistance:**It is computationally infeasible to find any pair (x, y) such that $h(x) = h(y)$.

In the past few years many attacks showed that the hash function $h_c(\cdot)$ of the Merkle-Damgaard construction couldn't maintain the three properties well.

In 1999,Dean [**?**] presented a second preimage attack on some hash functions

of M-D structure, he showed that fix-points of the compression function can be used for a second preimage attacks against long messages using $O(n \cdot 2^{n/2})$ time and $O(n \cdot 2^{n/2})$ memory (where n is the digest size). Later,the M-D structure was strengthened by coding the length of the message into the addition ,and in 2005 Ronald L. Rivest presented a way of "Dithering"[**?**] the operation of an iterated hash function,to overcome some "message expansion" attacks,but the "dithering" method was defeated by Kelsey and Schneier[**?**]. In 2004,Joux gave another attack , the multicollision attack [**?**] on cascade hash functions.In 2006, John Kelsey and Tadayoshi Kohno presented a generic preimage attack named Herding Attack[**?**].in 2008,Elena Andreeva , Charles Bouillaguet et al. developed a new generic long-message second preimage attack[**?**], based on combining the techniques in the second preimage attacks of Dean and Kelsey and Schneier with the herding attack of Kelsey and Kohno .

Recently,several hashing schemes were proposed ,such as the randomized hashing scheme proposed by Krawczyk and Halevi[**?**], the enveloped Damgaard-Merkle construction [**?**] proposed by Bellare and Ristenpart and HAIFA Scheme proposed by Eli Biham and Orr Dunkelman [**?**].

In this paper we'll present a concise proposal and try to fix the flaws of the Merkle-Damgaard construction completely,and certainly try to prevent varieties of those generic attacks.

We use a new mode called "Locking Abutting Blocks"(LAB Mode),it means that for a r-rounds(and each round contains 16 steps) compression function C and the chaining values h_i:

$h_i = C(h_{i-1}, M_i)$,the block input M_i will be in reality replaced by the two abutting blocks M_{i-1} and M_i , such that:

$$h_i = C(h_{i-1}, M_{i-1}, M_i).$$

This method seems a bit similar with Concatenate-Permute-Truncate design strategy,which used in several hash functions e.g. Hash Function Hamsi (Hamsi is a Second Round Candidate of the SHA-3 competition),but they are different at all,further more, we improve the LAB Mode by replacing the abutting blocks with two checksum-blocks $\sum M_{i-1}$ and $\sum M_i$,e.g.,such that:

$$h_i = C(h_{i-1}, \sum M_{i-1}, \sum M_i),$$

and the related work contains some hash functions which using checksums. Synchronously,we'll avoid the generic attacks which presented by Praveen Gauravaram and John Kelsey.

The rest of this paper is summarized as: In Section2 we give some related work.In Section3 we explain the symbols.In Section4 we describe the Merkle-Damgaard construction simply.In Section5 we explain the new mode of LAB,and give a detailed analysis . In Section6 we summary this paper.

For brevity, we assume the compression function is r-rounds(and each round contains 16 steps) ,the size m of each block is 1024 bits in this paper,ie.,each the subblock of word is 64 bit.

2 Related work

Hamsi

The Hash Function Hamsi is one of the candidates in second round SHA-3 competition.Hamsi is based on the Concatenate-Permute-Truncate design strategy used in several hash functions like Snefru[**?**] and Grindhal[**?**]. In addition to this approach,Hamsi uses a message expansion and a feedforward of the chaining value in each iteration. For each iteration of Hamsi-512 , the input includes a 512-bit chaining value and a 64-bit message, the concatenation of the 64-bit message is expanded to 512-bit , then connected with the 512-bit initial chaining value to be 1024 bit. Finally ,truncate the 1024-bit to produce 512-bit output value.

Hash Function with Linear-xor/additive Checksum

We quote *Cryptanalysis of a class of cryptographic hash functions* of Praveen Gauravaram and John Kelsey[**?**]: A family of variants of Damgaard-Merkle, in which a linear-XOR/additive checksum is computed over the message blocks, intermediate states of the hash function, or both. In a Damgaard-Merkle hash with a linear-XOR checksum, each bit of the checksum is a XOR function of the bits of the message, intermediate states or both; the checksum is processed as a final block after the padding and length encoding of the original message have been processed.E.g., the 3C construction[**?**] follow this pattern. F-Hash[**?**] uses a XOR checksum of the outputs of the compression function alongside a normal Damgaard-Merkle construction. Similarly, in a Damgaard-Merkle hash with linear-additive checksums, an additive checksum computed using message blocks, intermediate states or both is processed as a final block. The 256-bit GOST hash function specified in the Russian standard GOST [**?**] uses an additive checksum mod 2^{256} computed using 256-bit message blocks.

HAIFA

HAIFA is a framework proposed by Eli Biham and Orr Dunkelman, it can fix many flaws of Damgaard-Merkle construction .We quote Eli Biham and Orr Dunkelman below:

The main ideas behind HAIFA are the introduction of number of bits that were hashed so far and a salt value into the compression functions. Formally, a compression function $C : (0,1)^n \times (0,1)^m \times (0,1)^b \times (0,1)^s \rightarrow (0,1)^n$is proposed to substitute the form of M-D Structure $C_{MD} : (0,1)^n \times (0,1)^m \rightarrow (0,1)^n$, i.e., in HAIFA the chaining value h_i is computed as

$$h_i = C(h_{i-1}, M_i, \#bits, salt),$$

where n denotes the size of the chaining value,m denotes the block size for the compression function,b denotes $\#bits$,s denotes $salt$;$\#bits$ is the number of bits hashed so far and $salt$ is a salt value.

The following operations are performed:

1. Pad M according to the padding scheme .

2. Compute IV_n the initial value for a digest of size n using the prescribed way .

3. Iteratively digest the padded message using $C(\cdot)$, starting from the initial value IV_n and using the salt. In case an additional block is padded to the message, the compression function is called on this block with $\#bits = 0$.

4.Truncate the final chaining value if needed.

3 The Symbols In This Paper

M	denotes the message has been padded and Appended length as M-D structure,M can be divided to be L blocks: $M_1M_2...M_{L-1}M_L$.
M_i	denotes the i-th block,$1 \leq i \leq L$,it contains 16 words:$w_{i,j}$, $0 \leq j \leq 15$ i.e: $w_{i,0}, w_{i,1}, ..., w_{i,15}$.
m	denotes the size of each block M_i,
n	denotes the size of chaining value or the size of hash value.
$\overbrace{B \cdot k}$	denotes a k-block message,which contains k blocks : B_1,B_2,...,B_k.
A-B	denotes a 2-block message combined by Block A and Block B.
h_i	denotes the i-th output of chaining value.
$+$	denotes addition modulo 2^{64} .
$=$	denotes equal sign or assignment.
$\leftarrow$	denotes assignment or simultaneous assignment.
$\sum M_i$	denotes a checksum block, it contains 16 words: $\Sigma w_{i,0}, \Sigma w_{i,1}, ..., \Sigma w_{i,15}$. Define $\sum M_i = M_i + \sum M_{i-1}$; $\Sigma w_{i,j} = w_{i,j} + \Sigma w_{i-1,j}$.

4 The Normal Mode of M-D Structure

The Merkle-Damgard construction is the most common way to transform a compression function $C : \{0,1\}^n \times \{0,1\}^m \rightarrow \{0,1\}^n$ into a hash function $h_C(.)$,the Message Digest is n-bit value.

C denotes the compression function. M denotes the padded and Appended message , it is formatted as $16L$ $m/16$-bit words :$w_0, w_1, ..., w_i, ..., w_{16L-1}$ ie.,the message is made up of L m-bit blocks and each the block contains 16 $m/16$-bit words,for h_C:

h_i = Chaining variable ,$h_0 = IV$(given Initial Value),M_i = the i-th block

$h_i = C(h_{i-1}, M_i)$

$h_C(M) = h_L$

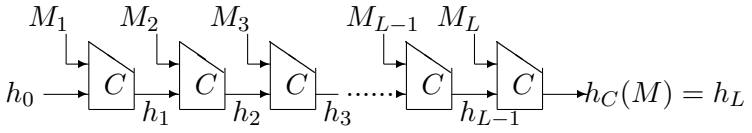


Fig.1. The Damgard-Merkle construction

5 New Structure

5.1 The Basis Of LAB Mode

For message $M(M_1M_2...M_{L-1}M_L)$, We give the compression function f of LAB :

$$h_i = f(h_{i-1}, M_{i-1}, M_i).$$

M_{i-1} and M_i are two successive blocks,we call them "LAB"Blocks,the i-th message block input M_i of M-D structure is replaced by M_{i-1} and M_i.(Fig.2)

For a r-round compression function f,the i-th iteration is:

Copy the i-th block M_i of 16 64-bit words into Buffer:
$A[j] \leftarrow B[j]$,$B[j] \leftarrow w_{16i+j}$, $0 \leq j \leq 15$.

First, compute with the 16 words of $B[j]$ in the first 2 rounds, then compute with the 16 words of $A[j]$ in the rest $(r-2)$ rounds.(Of course, it's better that the 16 words of $B[j]$ are used in inconsecutive rounds. e.g.:Round 1 and Round 3;and the best is the mixing (or rearranging the sequences)of the 32 words from $A[j]$ and $B[j]$.)

The hash function of LAB mode is given below :

Define an additive block M_0.

For i from 1 to L,

$h_0 = IV$(given Initial Value)

$h_1 = f(h_0, M_0, M_1)$

$h_i = f(h_{i-1}, M_{i-1}, M_i)$

$h_L = f(h_{L-1}, M_{L-1}, M_L)$

$h_f(M) = h_L$ Where $h_f(M)(= h_L)$ is the hash code.

We assume f is a n-bit ideal compression function,

$$f : (0,1)^n \times (0,1)^m \rightarrow (0,1)^n$$

For any input x,$f(x)$ has the three properties:

The complexity of finding a preimage or a second preimage is 2^n,and the complexity of finding a pair of collisions is $2^{n/2}$.Then,the two abutting blocks (M_{i-1}, M_i) are taken as an input of the compression function f.

Obviously, $f(h_{i-1}, M_{i-1}, M_i)$ also have the three properties.For i from 1 to L,each step the form of the compression function f of LAB mode maintain the properties,and ulteriorly,the chaining value h_i is limited by the last block M_{i-1} . This is the first characteristic of LAB mode.

For a n-bit hash function , the input of the $(i+1)$-th iteration increases a third part of the last block M_i.In reality this makes as M_i a connotative chaining variable for the $(i+1)$-th iteration ,the i-th iteration output is tantamount to a $(m+n)$-bit effectual chaining variable(We can also regard M_i as a concatenation as in Hamsi.).In a general way,$m > n$,it means the size of the effectual chaining variable has increased to more than $2n$,e.g., for a 512- hash code hash function,the size of the effectual chaining variable in each iteration is tantamount to $(512+1024)$ bits,thus,the size of effectual chaining variable of LAB Mode$(m+n)$ is more greater than the size of hash code(n),this is different from the others.

E.g.,the size of effectual chaining variable output in Hamsi

$$h_i = T \cdot P \cdot C(E(M_i), h_i)) \bigoplus h_{i-1}$$

The size of chaining variable was kept as n-bit, and the concatenation is expanded from 32-bit to 256-bit or 64-bit to 512-bit ,for Hamsi-512,the size of the effectual chaining variable outputed in each iteration is tantamount to $(512+64)$bits.

In reality,the compression function f of basic LAB Mode increases a lager size of effectual chain variable without requirements of intricate compute and larger memory,this is the second characteristic of LAB mode.The characteristics are suit to defeat Multicollisions Attack and Herding Attack .We will expound in next subsubsection.

5.1.1 Multicollisions Attack and Herding Attack

Multicollisions Attack

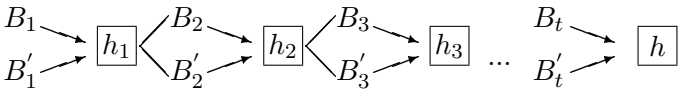
There are several generic attacks on the iterating functions of M-D construction,the first is Multicollisions[**?**].

We quote *Multicollisions in Iterated Hash Functions Application to Cascaded Constructions* :In a normal iterating function with M-D construction ,recall that a collision is a pair of different messages M and $M^{'}$ such that $H(M) = H(M^{'})$. Due to the birthday paradox, there is a generic attack that find collisions after about $2^{n/2}$ evaluations of the hash function, where n is the size in bits of the hash values.If there are t collisions of t pairs of different messages,then ,there can construct multicollisions of 2^t collisions.

Assume message M contains t blocks,$B_1, B_2, ..., B_t$,and blocks $B_1^{'}, B_2^{'}, ..., B_t^{'}$ are corresponding collision blocks,i.e.,

$$h_i = f(h_{i-1}, B_i) = f(h_{i-1}, B_i^{'}) \quad (1 \leq i \leq t)$$

Then ,each block B_i can be freely replaced by $B_i^{'}$ and 2^t collision messages can be gotten.



We assume f is an ideal compression function,in LAB Mode,

$$f : h_i = f(h_{i-1}, B_{i-1}, B_i)$$

Besides h_{i-1},each input contains the two abutting blocks of a iteration. We assume the different blocks B_i and $B_i^{'}$ yield a collision in the ith iteration(Although the complexity of finding a pair of collisions is $2^{n/2}$.),such that

$$f(h_{i-1}, B_{i-1}, B_i) = f(h_{i-1}, B_{i-1}, B_i^{'}) = h_i,$$

for the next((i+1)th) iteration:the part of the input $B_i \neq B_i^{'}$,so $f(h_i, B_i, B_{i+1}) = h_{i+1}$ and $f(h_i, B_i^{'}, B_{i+1}) \neq h_{i+1}$.

It means in LAB Mode ,even the corresponding collision blocks can be gotten by brute force with the complexity of $2^{n/2}$, they can't be freely substituted each other to build a new collision message.

Obviously,in LAB Mode,the 2^t-collision ,i.e, Multicollisions Attack is not tenable.

If we want to build a useable Multicollisions in LAB Mode, in each iteration,the first abutting block(m-bit) must be regarded as a available chaining variable (e.g., the Block B_{i-1} of the ith iteration: $f(h_{i-1}, B_{i-1}, B_i) = h_i$), and the size of chaining variable will become $(m + n)$ bits. By brute force,it requires approximately $t \times 2^{(m+n)/2}$ work .

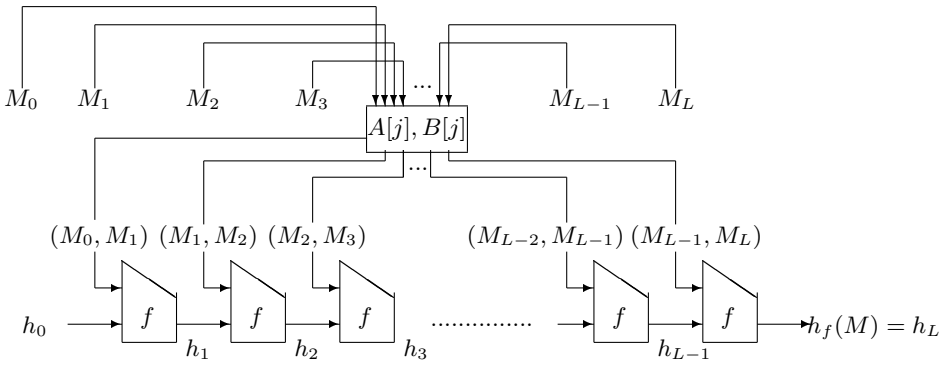


Fig.2. LAB construction

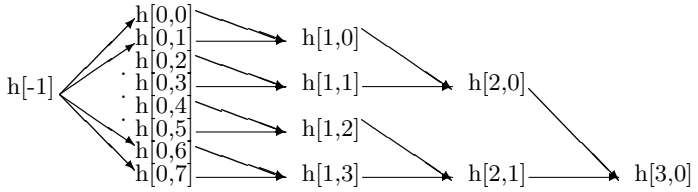
Herding Attack

The second generic attack on the iterating functions of M-D construction is Herding Attack.

Kelsey and Kohno give a diamond structure with width 2^k costs about $2^{k/2+n/2+3/2}$

work.

Diamond structure has total of $2^{k+1}-2$ intermediate hash values.Usually use only 2^k in widest level.



An attacker who can find many collisions on the hash function by brute force can first provide the hash of a message. The attacker first does a large pre-computation, and then commits to a hash value h. Later, upon being challenged with a prefix P, the attacker constructs a suffix S such that hash $(P \parallel S) = h$. Kelsey and Kohno ,Their paper introduced the "diamond structure"[5], which is reminiscent of a complete binary tree. It is a 2^ι multi-collision in which each message in the multi-collision has a different initial chaining value, and which is constructed in the pre-computation step of the attack. The herding attack on an n-bit hash function requires approximately $2^{2n/3+1}$ work[4].

We assume the attacker first does a large pre-computation and find many collisions on the n-bit hash function by brute force.By the previous analysis ,in LAB Mode,we can defeat this type of generic attack .

The first reason is : The multicollisions of Joux's can't be used in building any cascaded collisions message ,ie., we can't get a chosen target preimage message by combining the blocks pre-computed.

The second reason is :Any a chaining value output of a 2-block connected message doesn't only depend on chaining value input, it is also strictly related to the last block itself, this has broken the connected paths of the diamond tree.

The third reason is :Since each block outputs a large size of connotative chaining variable(the connotative size m and the effectual size of $(m+n)$ are much greater than the size n of CV.)and the effectual size of CV outputted is tantamount to $(m+n)$-bit, it make the size of intermediate chaining variable so large that the connection of the computation can't depend on the n-bit chaining variable only.

Obviously,in LAB Mode,Herding Attack is not tenable.

5.2 LAB's Family

By using checksum $\sum M_i$,we can build the forms of LAB:

a $h_i = f(h_{i-1}, M_{i-1}, \sum M_i)$;

b $h_i = f(h_{i-1}, \sum M_{i-1}, \sum M_i)$;

c $h_i = f(h_{i-1}, \sum M_{i-1}, M_i)$;

where $\sum M_i$ is the sum (modulo addition) of the i blocks ,it can also be the

xor operation of the i blocks.

For each unit $w_{i,j}$ of $M_i(w_{i,0}, w_{i,1}, ..., w_{i,15})$ and each unit $\Sigma w_{i,j}$ of Block $\sum M_i$ $(\Sigma w_{i,o}, \Sigma w_{i,1}, ..., \Sigma w_{i,15})$ $(1 \leq i \leq L$,$0 \leq j \leq 15)$,

$\sum M_i = M_i + \sum M_{i-1}$ i.e.:

$\Sigma w_{i,j} = w_{i,j} + \Sigma w_{i-1,j}$

Obviously,the LAB members keep the properties of the basic LAB since they keep successive blocks and checksums as input.

We provide a detailed form Type C below(for 64-bit words and 512-bit hash value)(Fig.3.).

1.Append padding bits and append length just as M-D Structure:

The message is padded with single 1-bit followed by the necessary number of 0-bits,so that its length l congruent to 896 modulo1024 $[l \equiv 896(mod 1024)]$,append a block of 128 bits as an unsigned 128-bit integer(most significant byte first)and contains the length of the original message.M denotes the message after padding bits and appending length. message. M is split to be L blocks:$M_1 M_2 ... M_L$

2.Difine a additive block M_0,encode the size of hash value n into M_0,just like HAIFA.

3.Define an initial value IV,Set buffer $A[j]$ and $B[j]$,for a r-round compression function f ,for i from 1 to L,do the following operations of each iteration,and get the hash value $h_f(M)$:

$h_0 = IV, \sum M_0 = M_0$

$h_i = f(h_{i-1}, \sum M_{i-1}, M_i)$

$h_L = f(h_{L-1}, \sum M_{L-1}, M_L)$

$h_f(M) = h_L$

4.Truncate the final chaining value if needed.

We provide details (e.g.):

$\diamondsuit$ The first iteration $(i = 1)$:

$\sum M_0 = M_0$; $A[j] \leftarrow \sum M_0$; $B[j] \leftarrow M_1$;

For the first 2 rounds,compute with the input of $A[j]$,and the rest $(r-2)$ rounds, compute with the input of $B[j]$.At the end of the first iteration,operate:

$A[j] \leftarrow (M_1 + \sum M_0)$.

$\diamondsuit$ For i ($2 \leq i \leq L$) , $B[j] \leftarrow M_i$,

For the first 2 rounds,compute with the input of $A[j]$,and for the rest $(r-2)$ rounds, compute with the input of $B[j]$,at the end of the iteration,operate:

$A[j] \leftarrow (M_i + \sum M_{i-1})$

In reality,for a r-round compression function,it's better that the sequences of the 32 words are mixed from $A[j]$ and $B[j]$.

5.3 Second Preimage Attacks And The Generic Attacks Proposed By Praveen Gauravaram And John Kelsey

The third generic attack on the iterating functions of M-D construction is Second preimage attack.

The second preimage attack of Dean means is ,to insert a block (or blocks)at so called a fixed point i-th block,then make a preassigned output CV_i equal to the input CV_i,thus,the attacker can get a new message with a same hash code of the primary message.

Although M-D Structure strengthened by encoding the length into the last block to prevent some second preimage attacks which messages with free length,the "message expansion" attack (proposed by Kelsey and Schneier) avoids the strengthening by repeating the inserted block to satisfy the length. And a way of "dithering" proposed by Ronald L. Rivest can't block the second preimage attacks proposed by Andreeva et al.

The hashes with linear-xor/additive checksum can easily thwart the second preimage attacks,for the length of message is restricted to checksum[**?**].The linear-XOR/additive checksums in the Damgaard-Merkle hashes thwart the known techniques of performing long message second preimage and herding attacks [**?**]. However,the hashes with linear-xor/additive checksum are defeated by Praveen Gauravaram and John Kelsey [**?**],who use new techniques of Extending Joux 1-block multicollision attack and Checksum Control Sequences.

Checksum Control Sequences(CCS)is as a chunk of data which lets an attacker to control the checksum value in the hash functions with linear checksums. The attacker constructs the CCS by building a Joux multicollision of the correct size using a random choice of message blocks. He then uses the CCS to actually control the checksum using a checksum control algorithm without changing any intermediate hash value on the iterative chain.

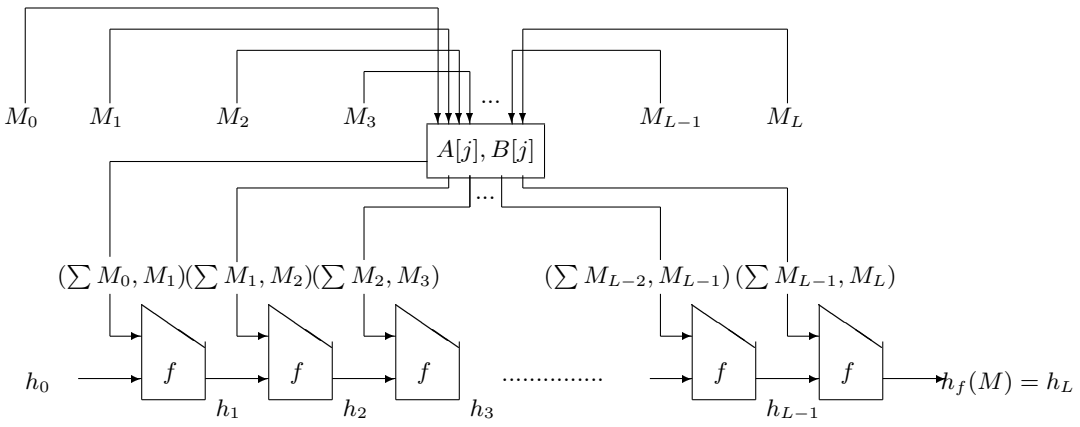


Fig.3. LAB Form C

LAB Mode with checksum e.g.LAB Form C can easily overcome this new attack of Praveen Gauravaram and John Kelsey.

1.Joux's multicollision attack is not tenable in LAB Mode (with checksum) no matter the multicollisions are" 1-block" or "multi-block" ones.

a.The first,the technique of "multi-block" multicollision is based on Joux's "1-block"multicollision .In LAB Form C,an attacker can't build a "multi-block" multicollision by using the technique of " 1-block"multicollision ,and he can't control the chaining values.This is different between LAB mode and the other hashes with linear-xor/additive checksum.

b.Assume the attacker get t pair of collision block groups(See Fig.4.),the first pair of groups are G_1 and $G_1^{'}$,(i.e.,G_1 and $G_1^{'}$ are a pair of collision messages.) each of them contains k_1 blocks.Each the second pair of groups contains k_2 blocks ,...,and so on,the last group contains k_t blocks.

For G_1 , $G_1^{'}$ and a n-bit hash function,by brute force ,it requires about $2^{n/2}$ hash function computations to find a collision with 0.5 probability, such that $CV_{k_1} = CV_{k_1}^{'}$.

The state of the first pair of groups outputting are"$\sum G_1, CV_{k_1}$" and "$\sum G_1^{'}, CV_{k_1}^{'}$". If $\sum G_1 \neq \sum G_1^{'}$,which means the initial state of the next groups are different and therefore we can't control the chaining values anymore.Then,it requires $\sum G_1 = \sum G_1^{'}$ synchronously,in practice, this means the size of intermediate effectual chaining value is tantamount to $(n+m)$ (where m is the block size.)E.g,$n = 512$,$m = 1024$,the size is tantamount to $(512 + 1024) = 3n$,by brute force,it requires about $2^{n/2}$ hash function computations to find a collision,if the attacker want to structure 2^t available multicollisions by brute force,it requires a computational work of $t \times 2^{3n/2}$ computations of the compression function.It is not worth the candle, and it's infeasible.

2.If we change any a block of a message in LAB Mode, exactly the input of the next iteration has been changed, the checksum will change and the output of chaining value(the intermediate hash value) will change,and the other blocks will change so on,...,The attacker can't synchronously control the intermediate hash values and checksums at all.

So,a random choice of message blocks can't achieve.

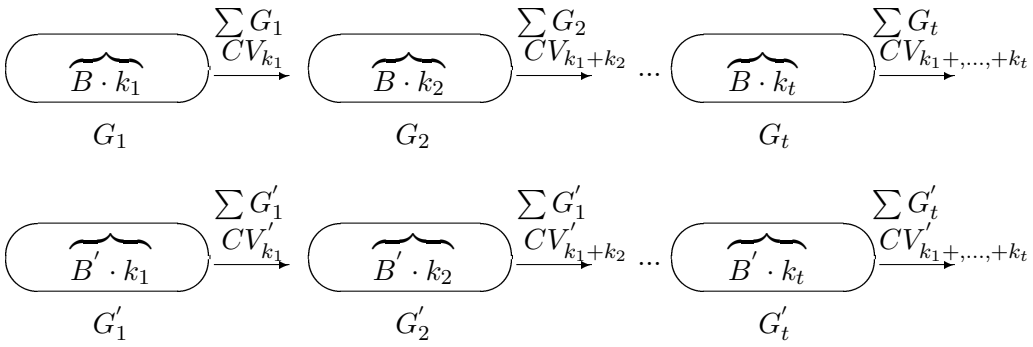


Fig.4. Collision Block Groups OF LAB Mode C

By putting the checksum and message block together ,we make the the checksum and block as input of each iteration,if the intermediate checksum has any change,the intermediate chaining value output will change immediatly . So,LAB Forms with checksum are different from other hash functions with linear-xor/additive checksums.

5.4 In Contrast With HAIFA Structure

We can compare LAB structure with HAIFA structure .(Fig.5)

In HAIFA structure ,each iteration inputs the effective size of chaining variable is tantamount to $(n + \#bits + salt)$ bits,maybe this size is not the most sufficient.

In LAB structure,the size of the effectual chaining variable is so large, for each iteration ,the size of the chaining variable is $(m + n)$-bit.

6 Summary

In LAB form with checksum,the abutting 2 blocks(at least one of them is a checksum block) are inputted together in a iteration, we can regard the last block as the connotative chaining variable in each iteration (and we can also regard the last block as the feedforward of the chaining value in each iteration). Since the connotative chaining variable is the last block itself,it means the effectual chaining variable will different if any block has been substituted with a different one .Thus,the multicollisions attack is struck at the foundation,and the herding attack also loses it's foundation .

The LAB form with checksum is easy to defeat the 2nd Preimage attack.

The form of the table below is from HAIFA .

Type of Attack	Ideal Hash Function	MD	HAIFA fixed salt	HAIFA with(distinct)salts	LAB (Form C)
	=	$\geq$	$\geq$	$\geq$	$\geq$
Preimage	2^n	2^n	2^n	2^n	2^n
one-of-many pre-image ($k^{'} < 2^s$targets)	$2^n/k^{'}$ ($k^{'} < 2^s$targets)	$2^n/k^{'}$	$2^n/k^{'}$	2^n	2^n
Second-pre-image (k blocks)	2^n	$2^n/k$	2^n	2^n	2^n
one -of- many second pre-image(k blocks in total,$k^{'} < 2^s$messages	$2^n/k^{'}$	$2^n/k$	$2^n/k^{'}$	2^n	2^n
Collision	$2^{n/2}$	$2^{n/2}$	$2^{n/2}$	$2^{n/2}$	$2^{n/2}$
Multi-collision (k-collision)	$2^{n(k-1)/k}$	$\lceil \log 2^K \rceil 2^{n/2}$	$\lceil \log 2^K \rceil 2^{n/2}$	$\lceil \log 2^K \rceil 2^{n/2}$	2^n
Herding Offline:	–	$2^{n/2+t/2}$	$2^{n/2+t/2}$	$2^{n/2+t/2+s}$	–
Herding online:		2^{n-t}	2^{n-t}	2^{n-t}	–

Fig5.Complexities of Attacks on Merkle-Damgaard and HAIFA Hash Functions with Comparison for an Ideal Hash Function and LAB Form C

Since LAB structure increases the size of the connotative chaining variable by the last block itself,this doesn't need requirements of intricate computing and large memory ,we can develop it to be a multi-block LAB structure.E.g.,a 3-block LAB structure:

$$h_i = f(h_{i-1}, M_{i-2}, M_{i-1}, \sum M_i)$$

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