

# [MS-RDC]: Remote Differential Compression Protocol Specification

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# 1 Introduction

**Remote differential compression (RDC)**, a Microsoft proprietary compression algorithm, enables efficient synchronization of **files** with a remote source by using compression techniques to minimize the amount of data sent between a **client** and **server**. The data is usually, though not always, in the form of a **file** stored on a **file** system. Unlike more traditional compression algorithms that rely on some regularity in the data to be compressed, **RDC** breaks a **file** into **chunks**. The **chunks** not already present on the **client** can be identified by the application transferring the data stream. The application can then transfer the missing **chunks** from the **server**.

## 1.1 Glossary

**Chunks:** The pieces of a **file** defined by the **cut points**.

**Client:** For the purposes of this document only, the **client** is the destination machine, or the machine receiving a **file** that has been compressed by **remote differential compression (RDC)**. It does not refer to a particular operating system being run, or to any function of the machine other than receiving data compressed by **RDC**.

**Collision-Resistant Hash Function:** A **hash function** having the property that (in practice) differing inputs do not produce the same hash (or collide).

**Cut Points:** The locations in a **file** where **remote differential compression (RDC)** has determined boundary points between blocks (or **chunks**). The **cut points** for a particular **file** depend on the content of the **file** and the parameters with which **RDC** is running.

**File:** A **file** is a typed data stream. For the purposes of this document only, **file** does not imply storage of the data stream in any particular medium or with any particular organization, or, for example, in a file system (*italic* is used when referring to traditional *files*).

**Hash Function:** A function that takes an arbitrary amount of data and produces a fixed length result (or hash) that depends only on the input data. A **hash function** is sometimes termed a message digest or a digital fingerprint.

**Hash Window:** The length in bytes of the domain of the **rolling hash function** (that is, the parameter  $n$  in the definition of **rolling hash function**).

**Horizon:** An integer parameter of the **RDC FilterMax algorithm**. It refers to the number of consecutive hash values on both sides of a **file** offset.

**Local Maximum:** A pair consisting of an offset  $i$  in a **file** and the hash value  $h(b_{i-\text{Hash Window}} \dots b_i)$  that has the property that for all  $j \geq 0$ , such that  $i - \text{horizon} \leq j \leq i + \text{horizon}$ ,  $j = i$  OR  $h(b_{j-\text{Hash Window}} \dots b_j) < h(b_{i-\text{Hash Window}} \dots b_i)$ , where for all  $k < 0$ ,  $b_k$  is defined to be 0. Local maxima are used to find **cut points** by the **RDC FilterMax algorithm**.

**MD4:** Message Digest 4, as specified in [\[RFC1320\]](#). MD4 is a collision-resistant, non-rolling **hash function** that produces a 16-byte hash. While MD4 is no longer considered to be cryptographically secure, **remote differential compression (RDC)** does not rely on cryptographic security in its **hash function**.

**Min-Wise Independent Hash Functions:** A set  $H = \{ H_1, H_2, \dots, H_n \}$  of **hash functions** is said to be Min-Wise Independent if, for any input  $D$  and for any subset  $X$  of  $\{1, \dots, n\}$ , any index  $i$  of  $X$  has an equal probability of yielding the smallest value  $H_i(D)$  of the values  $H_j(D)$  for  $j$  in  $X$ .

**RDC FilterMax Algorithm:** The algorithm that **remote differential compression (RDC)** uses to determine the **cut points** in a **file**. The **RDC FilterMax algorithm** has the property that it

will often find **cut points** that result in identical **chunks** being found in differing **files**, even when the **files** differ by insertions and deletions of bytes, not simply by length-preserving byte modifications. See section [3.1.5.1](#).

**Recursion Level:** For very large **files**, even the **signature file** may be large. To reduce the bandwidth needed to transfer **signature files**, **remote differential compression (RDC)** may be used to reduce the number of bytes that must be moved from **server** to **client** to transfer the **signature file**. This process may be repeated a number of times, producing successively smaller **signature files**. The **recursion level** is the number of times it is repeated. The first **signature file** is **recursion level 1**. The **source file** is referred to as being at **recursion level 0**.

**Remote Differential Compression (RDC):** In general, the term **remote differential compression (RDC)** may refer to any of a class of compression algorithms designed to compare two **files** residing on different machines without requiring one of the **files** to be transmitted in its entirety to the other machine. In this document, unless otherwise noted, the terms **remote differential compression** and **RDC** always refer to the **RDC** algorithm developed by Microsoft.

**Rolling Hash Function:** A **hash function** that can be computed incrementally over a set of data. Given an arbitrary integer  $n \geq 0$ , some bytes  $b_0 \dots b_{n-1}$ , and their hash  $h(b_0 \dots b_{n-1})$ , a **hash function**  $h$  is a **rolling hash function** if one can compute  $h(b_1 \dots b_n)$  in time that does not depend on  $n$ .

**Seed File or Seed Data:** A **file** or **files** on the **client** used to supply data used in reconstructing the **source file**. **remote differential compression (RDC)** may use an arbitrary number of **seed files** in the process of copying a single **source file**. Sometimes called seed. Selecting **seed files** is implementation specific, but can be guided by using **similarity traits**. For how Windows selects **seed files**, see section [3.1.5.4.1](#).

**Server:** For the purposes of this document only, the **server** is the source machine, or the machine from which a **file** is being transferred after compressing it with **remote differential compression (RDC)**. It does not refer to a particular operating system being run, or to any function of the machine other than holding **source data** for **RDC**.

**Signature:** A structure containing a hash and block **chunk** size. The hash field is 16 bytes, and the **chunk** size field is a 2-byte unsigned integer. See section [2.2.2.1](#).

**Signature File:** A **file** containing the **signatures** of another (source) **file**. There is a simple header that identifies the type of the **file** as a **signature file**, the size of the header itself, and the **remote differential compression (RDC)** library version number. Following the header are the **signatures** from the **source file** in the order they are generated from the **chunks**. See section [2.2.2](#).

**Similarity Data:** Information on a **file** that can be used to determine an appropriate **seed file** to select to reduce the amount of data transferred. **Similarity data** can be computed in any implementation-specific way. For Windows behavior, see section [3.1.5.4](#).

**Similarity Traits:** **Similarity data** consists of one or more traits. Each trait summarizes an independent feature of a **file**. The features are computed by taking **min-wise independent hash functions** of a **file's signatures**. For how traits are computed, see section [3.1.5.4](#). **Similarity traits** are used in selecting **seed files**.

**Source File or Source Data:** A **file** on a **server** that is to be copied by **remote differential compression (RDC)**. Sometimes referred to as source.

**Target File:** A **file** on the **client** that is the destination of a **remote differential compression (RDC)** copy.

**MAY, SHOULD, MUST, SHOULD NOT, MUST NOT:** These terms (in all caps) are used as described in [\[RFC2119\]](#). All statements of optional behavior use either MAY, SHOULD, or SHOULD NOT.

## 1.2 References

### 1.2.1 Normative References

We conduct frequent surveys of the normative references to assure their continued availability. If you have any issue with finding a normative reference, please contact [dochelp@microsoft.com](mailto:dochelp@microsoft.com). We will assist you in finding the relevant information. Please check the archive site, <http://msdn2.microsoft.com/en-us/library/E4BD6494-06AD-4aed-9823-445E921C9624>, as an additional source.

[RFC1320] Rivest, R. "The MD4 Message-Digest Algorithm", RFC 1320, April 1992, <http://www.ietf.org/rfc/rfc1320.txt>

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997, <http://www.ietf.org/rfc/rfc2119.txt>

### 1.2.2 Informative References

[FIPS180-2] Federal Information Processing Standards Publication, "Secure Hash Standard", FIPS PUB 180-2, August 2002, <http://csrc.nist.gov/publications/fips/fips180-2/fips180-2.pdf>

[LBFS] Muthitacharoen, A., Chen, B., and Mazieres, D., "A Low-Bandwidth Network File System", October 2001, <http://sosp.org/2001/papers/mazieres.pdf>

[MS-FRS2] Microsoft Corporation, "[SD Microsoft Distributed File System Replication Protocol Specification](#)", July 2006.

[MSDN-RDCAPI] Microsoft Corporation, "Remote Differential Compression", <http://msdn2.microsoft.com/en-us/library/aa373254.aspx>

[UASDC] Ziv, J. and Lempel, A., "A Universal Algorithm for Sequential Data Compression", May 1977, <http://ieeexplore.ieee.org/iel5/18/22696/01055714.pdf>

## 1.3 Protocol Overview (Synopsis)

**Remote differential compression (RDC)** is a compression algorithm that is used in other protocols, but it is not a protocol itself.

Traditional compression algorithms operate by finding some kind of redundancy in the **file** to be compressed, and then represent it more compactly. For example, the Lempel-Ziv algorithm (for more information, see [\[UASDC\]](#)) finds repeated substrings in the **source file** and replaces second and successive instances of them with references to the initial string in the compressed **file**. By contrast, **RDC** tries to find blocks of data that are identical between the **source file** (on the **server**) and a set of **seed files** (on the **client**). This makes it possible for the protocol that is transferring the **file** between two machines to reduce the number of bytes transferred between the **server** and **client** when reconstructing the **source file** on the **client**.

The fundamental observation that drives **RDC** is this: By dividing a **file** into **chunks** and determining what **chunks** are already present on the **client**, a correct copy of a **source file** can be

constructed on the **client**. To accomplish this, it is only necessary to transfer those **chunks** not already present on the **client**, and combine them in the proper order with those **chunks** that are already present on the **client**. If many **chunks** of the **source file** are already present on the **client**, this technique can greatly reduce the amount of data that needs to be transferred compared to sending the entire **source file** from the **server**.

The set of **chunks** that make up a **file** can be expressed in far fewer bytes than the entire **file** by means of a **signature file**. The **signature** of a **chunk** is its length and a collision-resistant hash of its contents. Because hashes produce small, fixed-size outputs, for even modest-size **chunks**, the **signature** will be much smaller than the **chunk**.

Any method of determining **chunk** boundaries will suffice to produce correct behavior. However, because it is common to create a **file** by inserting or deleting bytes from a previously existing **file**, or by combining several previously existing **files**, it is advantageous to have a chunking method that can find equal **chunks** at some point after the insertion or deletion. A necessary consequence of this property is that the chunking method needs to be data dependent. It cannot simply use fixed offsets.

The **RDC** chunking method computes a rolling hash over the data using the H3 **hash function** (see section 3.1.5.1.1) and selects as **chunk** boundaries the offsets that have the largest value of H3 within a given **horizon**. Because this computation depends only on the bytes within the **horizon** (plus possibly one **hash window** size of bytes before the **horizon**), any change outside of the **horizon** will not affect the **chunk** boundaries. Thus, the chunking will produce identical **chunks** sufficiently far away from the change, including insertions and deletions.

This idea was the basis of MIT's Low-Bandwidth Network File System (LBFS) (for more information, see [LBFS](#)), although LBFS differs from **RDC** in many details.

In overview, **RDC** is meant to be used as part of a network protocol that engages in a handshake of the form:

1. Machine A sends Machine B a request to transfer *file*  $f_B$ .
2. Machine B partitions *file*  $f_B$  into **chunks** and computes the **signature** for each of the **chunks**. Machine B sends its list of **chunk signatures**,  $\text{SigB}_1 \dots \text{SigB}_n$ , to Machine A. This list provides the basis for Machine A being able to reconstruct *file*  $f_B$ .
3. Using **similarity data** (see section 3.1.5.4), Machine A selects a *file*  $f_A$  as a **seed file** and partitions it into **chunks**. It computes a **signature** for each **chunk** (see section 3.1.5.2).
4. As Machine A receives the **chunk signatures** from Machine B, it compares the received **signatures** against the set of **signatures**  $\text{SigA}_1, \dots, \text{SigA}_m$  that it has computed on its **seed file** (that is, *file*  $f_A$ ) in step 2. As part of this comparison, Machine A records every distinct **signature** value it received from Machine B that does not match one of its own **signatures**  $\text{SigA}_k$  computed on the **chunks** of *file*  $f_A$ .
5. Machine A sends a request to Machine B for all the **chunks** whose **signatures** were received in the previous step from Machine B, but that did not have a matching **signature** on Machine A. The **chunks** are requested by offset and length in *file*  $f_B$  based on corresponding information that was sent in step 2.
6. Machine B sends the contents of the requested **chunks** to Machine A.
7. Machine A reconstructs *file*  $f_B$  by using the **chunks** received in step 6 from Machine B, as well as its own **chunks** of *file*  $f_A$  that matched **signatures** sent by Machine B in step 4. After this reconstruction step is complete, Machine A has completed the transfer of  $f_B$ .



**RDC** takes advantage of the fact that a list of **signatures** can be treated as a binary blob, and therefore can be treated as a **signature file**, which is amenable to **RDC**. Thus, a recursive application of **RDC** is possible by feeding the **signature file** obtained in step 2 to **RDC**. This is useful in cases in which the *file* to be transferred is so large that even its **signature file** is large relative to the set of bytes that have changed.

## 1.4 Relationship to Other Protocols

**Remote differential compression (RDC)** is not a protocol, but provides a way for other protocols to increase their efficiency when these protocols are involved in moving **files** from one machine to another. The Distributed File System (DFS) replication system (for more information, see [\[MS-FRS2\]](#)) is the only application that currently uses **RDC**.

## 1.5 Prerequisites/Preconditions

None.

## 1.6 Applicability Statement

**Remote differential compression (RDC)** can be used any time it would be helpful to store or transmit the differences between a **source file** and a set of **seeds** instead of storing or transmitting the **source file** in its entirety. **RDC** is only useful when there is data in common between the **files** being compared. However, **RDC** is the compression and differencing algorithm and is in no way involved with the actual data transfer.

An example of when it may be helpful to use **RDC** is when collaborators work on shared documents over a wide-area, low-bandwidth network. During a round of edits, it is advantageous to work on a local copy of the shared document. Thus, the shared document should be copied between the involved sites when a different editor takes over. Instead of copying over the entire contents of the document, it might be beneficial to copy over only what has been edited.

## 1.7 Versioning and Capability Negotiation

**Remote differential compression (RDC)** supports versioning through a version number in the **signature** header. See section [2.2.1.1](#). The version number **MUST** be 1.

## 1.8 Vendor-Extensible Fields

None.

## 1.9 Standards Assignments

None.

## 2 Messages

### 2.1 Transport

**Remote differential compression (RDC)** does not have a defined transport. It is entirely up to the application using **RDC** to provide the necessary data to the **client** and **server**.

### 2.2 Message Syntax

This section defines the format of the **files** that **Remote differential compression (RDC)** uses between the **client** and **server**.

All multi-byte integers represented in this document are in least-significant-byte-first order, colloquially called little-endian.

All integer constants that appear are in decimal, unless otherwise noted.

#### 2.2.1 Common Data Types

##### 2.2.1.1 RDC Version

**Remote differential compression (RDC)** version represents a version of **RDC** and is used to determine when **clients** and **servers** can interoperate.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
LibraryVersion																BuildNumber															

**LibraryVersion:** A 16-bit unsigned integer that indicates the version of the **RDC** implementation. The value of LibraryVersion MUST be set to 0x0001.

**BuildNumber:** A 16-bit unsigned integer that indicates the version of the software implementing the algorithm. The value of BuildNumber MUST be set to 0x0001.

### 2.2.1.2 FileHeader

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
HeaderSize																															
Version																															
MinVersionRequired																															
Padding																															
FileType																															
FileType (continued)																															

**HeaderSize:** The size of the FileHeader structure in bytes. MUST be 0x00000018.

**Version:** The version of **remote differential compression (RDC)** that generated this **signature file**. See section [2.2.1.1](#).

**MinVersionRequired:** An **RDC** version representing the lowest version of **RDC** that can understand this **signature file**. See section [2.2.1.1](#). It MUST be 0x00010001.

**Padding:** Reserved for future use; MUST be 0, and ignored on receipt.

**FileType:** An unsigned 64-bit integer that indicates the **RDC** file type of a *file*. The value of FileType MUST be set to 0x00000001.

### 2.2.2 Signature Files

The **signature file** consists of a header and zero or more **RDC chunk signatures**, as shown below.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FileHeader (a total of 6 rows, or 24 bytes)																															
Zero or more ChunkSignatures																															
(Each ChunkSignature is a total of 4 ½ rows, or 18 bytes)																															

**FileHeader:** A FileHeader structure, as specified in section [2.2.1.2](#). The FileType field of the FileHeader structure MUST be 1 for a **signature file**.

**ChunkSignatures:** Zero or more ChunkSignatures. See section [2.2.2.1](#).

### 2.2.2.1 ChunkSignature

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
HashValue (a total of 4 rows or 16 bytes)																															
BlockLength																															

**HashValue:** MUST be the **MD4** digest of a data **chunk**.

**BlockLength:** A 16-bit unsigned integer that contains the length of the data **chunk** that is represented by this **signature**. The block length MUST be nonzero.

**Bits 16–31 of the Last Row:** Because a **signature** is 18 bytes long, and because the 32-bit width of the rows in the diagram does not evenly divide into 18 bytes, the last 16 bits of the diagram is space that is not part of the **signature** at all. This fact is represented by an empty area in the diagram above.

### 2.2.3 Similarity Data

Some applications of **remote differential compression (RDC)** will include **similarity data** in their network protocols. The format of the **similarity data** is as follows.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
t0								t1								t2								t3							
t4								t5								t6								t7							
t8								t9								t10								t11							
t12								t13								t14								t15							

**t0 Through t15 Similarity Traits:** See section [3.1.5.4](#). Each **similarity trait** is an 8-bit unsigned integer value.

## 3 Protocol Details

### 3.1 Common Details

The **client** and **server** MUST compute identical **signatures** for identical **chunks**, and both the **client** and **server** SHOULD use the same algorithm and the same parameters for dividing **files** into **chunks**. This section specifies these processes. [<1>](#)

#### 3.1.1 Abstract Data Model

This section describes a conceptual model of possible data organization that an implementation maintains to participate in this protocol. The described organization is provided to facilitate the explanation of how the protocol behaves. This document does not mandate that implementations adhere to this model as long as their external behavior is consistent with what is described in this document.

**H3 Lookup Table:** A table containing 256 32-bit unsigned integers used in computing the H3 **hash function**. The entries to the table are indexed from 0 to 255. This table is constant (that is, the values in this table do not change during the execution of **RDC**).

#### 3.1.2 Timers

There are no timers in the **RDC** chunking and **signature** generation components.

#### 3.1.3 Initialization

After initialization, the H3 lookup table MUST contain the following data.

Index	Values			
0	0x5e3f7c48	0x796a0d2b	0xbecd4e32	0x6f16159c
4	0x687312bc	0x12a6f30a	0x8fca2662	0x79b83d14
8	0x3fab3f30	0x984d6ca2	0x4df5fe6c	0x4acd3196
12	0x6245ad21	0x3a15e5ba	0x90db6499	0x05aacb6b
16	0x791cf724	0x504cd910	0x98093570	0x090392df
20	0xf193e5b8	0x42023c5b	0x80a95c6a	0x11e676be
24	0xc70f2117	0xeed4587f	0x6479e9bd	0x1b0c427c
28	0x410486ba	0x30f5b837	0xf957d307	0x1535f121
32	0xabe45e90	0x7a1ab8f0	0x1c6887e4	0x4170b7ba
36	0x8b491bed	0x5c920e73	0x1b1ed791	0x7a0ed482
40	0xcce86619	0x45dc7290	0x57e71362	0x2e24f01c
44	0x0a0637f3	0x0e8c5565	0x15944012	0x34f7eeea
48	0xbc628141	0x1e200874	0xe9244379	0x3e63aeca

Index	Values			
52	0x7a3b3cce	0x73f8a245	0xd734e215	0x834fa434
56	0xf96a0904	0xfb39a424	0x0bfa963a	0x9b236ee2
60	0xa2131005	0x3eb70acf	0x2907bcd8	0x3f685f3a
64	0x3765fd37	0x1c1c34d2	0x03a95179	0x024be6c3
68	0x06128960	0x844e7490	0xe2b371a3	0x3382909c
72	0x3d519a77	0x90971ec9	0x6ea745e5	0x490b3a5c
76	0x7f3916f7	0xbc150351	0x241a7ba0	0xec93c2bb
80	0x6c7083aa	0xf3937751	0xe6aa1df1	0x129fc001
84	0xb90709b9	0x7e59a4fc	0x4509e58a	0x8a93ed43
88	0x6934ce62	0x8ec6af1a	0xf36581a9	0x53d01d93
92	0xb34eef69	0x08494a84	0x0f6dff34	0x74729aa3
96	0x48b5475f	0xb986dc84	0xd0424c8d	0xb72ad089
100	0x0adbdbd8	0x824fdbbe8	0x99ad1058	0x98faec38
104	0xe746242b	0x2b7ee7fc	0x2e151fa7	0x6413270f
108	0x68ed7239	0x7729e2d3	0x5697b3a5	0x0b90a6c3
112	0xdf7cefcf	0xded46a48	0x46956888	0xb3bb6dc4
116	0xe987578f	0xf82e74b7	0xc8eeeba4	0xdd960ff9
120	0x482ed28d	0x4f343078	0x563ab8a4	0x3ec7aa0d
124	0x2481d448	0x5fe98704	0x5aafc580	0x841d81ec
128	0xae7fe8fd	0x6b31ccb6	0x911ebdd4	0x75f4703d
132	0xe6855a0f	0x6184b42e	0x147a4a95	0x39528e48
136	0xe975b416	0x3cba13d3	0x1e23e544	0xf7955286
140	0xa5f96b7f	0xaa697aa	0x29e794e3	0x87628c09
144	0xfeebf5f1	0xf8b070cd	0xe361b627	0x8c7a8682
148	0x69cab331	0xca867ad1	0xd0151a96	0xfc19a6b9
152	0x6d7439e7	0x64cd62ac	0x4a650747	0x9ddbfa28
156	0x337c8bed	0xf12a6860	0x3767ffd3	0x13559ced
160	0x71ac2011	0xc11dc687	0x260b7105	0xc13bca0c
164	0xcd0af893	0x793b54e6	0x89d27fc3	0xc6bd1c88

Index	Values			
168	0xe3337313	0x387bc671	0x61280de4	0x76941a36
172	0xaa52a2b9	0x6d7cb52c	0x18ff4d70	0x8987cf38
176	0x306e47ed	0xf7df8135	0x18a8e024	0xc9eb085f
180	0xc1a7c769	0xd5667a12	0x9c8be93a	0x028781b1
184	0x6213dada	0x07fef4f5	0x5e6bf91d	0x469ea798
188	0xb9654a37	0x1cb5e74e	0x525d502d	0xe805ec68
192	0xdd8c4320	0x7890848f	0x61e59c8e	0x1d99f9ef
196	0x25b60b20	0x2f198088	0xe01b6926	0xffa4917f
200	0xb2fa0f22	0xee8ac924	0x18a1c5a7	0xb76d8d7f
204	0x88ad5e0d	0x7b3fb12b	0xc8a91add	0x762a6f4e
208	0x056fad31	0xebecfab8	0xea54cd17	0x71f5af9f
212	0xfaececa1	0x08a52f4d	0xbb5efebe	0x5bc04c2
216	0xcb2530b0	0x01bb862b	0xbb5d54f0	0x404deb4b
220	0x038658bd	0x09399005	0xdd862c8	0x8985776f
224	0xcfcfd717	0xbec756cb	0x52aecc5a	0x09ac3f62
228	0x62c1c6fb	0x76cc3221	0xcde6d028	0x844d9291
232	0xc143eeac	0x0ea5e772	0x8855456e	0xeb03a426
236	0x3398475d	0x73dc8107	0x681605d0	0xd18b6264
240	0x934e43eb	0x59e76d21	0xd3ce2b77	0x4ccfee1c
244	0x2f4af76d	0x8b12a309	0x849bb415	0xf45ad809
248	0xc7bcae7	0xac891c35	0x59db2274	0xbcd71393
252	0x2c9b1705	0xcb536a69	0xb2800f00	0x111313fc

The H3 lookup table is constant and so MUST NOT change at any time.

**Note** This data can be generated by setting the first 16 bytes of the table (that is, the first four 32-bit unsigned integers) to the **MD4** hash of 16 bytes of zeros. Each successive 16 bytes of the table is the **MD4** hash of the previous 16 bytes of the table. Implementing this procedure results in running the **MD4** hash 64 times.

### 3.1.4 Higher-Layer Triggered Events

There are no higher-layer triggered events in the **RDC** chunking and **signature** generation components.

### 3.1.5 Message Processing Events and Sequencing Rules

Because **RDC** is not a protocol, it does not have messages. Instead, this section specifies the actions upon getting a request to determine the **chunk** boundaries in a **file**, or to compute the **signature** for a **chunk**.

Section 3.1.5 contains a number of instances of pseudocode. In this pseudocode, operator precedence is the same as in the C language. The symbol "==" is used for assignment, meaning that the variable appearing to the left of "==" thereafter assumes the value to the right. The symbol "\" indicates a set difference, and is usually pronounced as the English word "without." For example,  $\{a,b,c\} \setminus \{b\} = \{a,c\}$ .

#### 3.1.5.1 Chunk Generation

This section specifies the **RDC FilterMax algorithm**, which is used to generate **chunks**.

**RDC chunk** generation is initiated by the protocol or application that is using **RDC** for efficient data transfer. For an example, see [\[MS-FRS2\]](#) section 3.2.1.5.

**RDC chunk** generation takes as input a file and two parameters, the **hash window**, and the **horizon** and produces a set of offsets into the **file** that indicates the start of the **chunks** of the **file**. Prior to their use, the **hash window** and the **horizon** MUST be negotiated between the sender and receiver of the **file** to ensure that **chunks** are generated consistently on both ends. Negotiation of **hash window** and **horizon** is application specific and is not addressed in this document. [<2>](#)

With each **chunk**, **RDC** computes a **signature**. See section [3.1.5.2](#).

##### 3.1.5.1.1 H3 Hash

**RDC** uses a **rolling hash function** called H3 in determining its **chunk** boundaries. H3 computes the hash of the **hash window** bytes (denoted as windowSize below) up to and including a particular byte in the **file**. Because it is a **rolling hash function**, the H3 hash of a given range is defined in terms of the hash of the range starting and ending one byte earlier.

shift\_amount is an unsigned 32-bit integer that depends only on windowSize, and is used in computing H3. The shift\_amount is calculated as follows.

```
shift_amount := 1
i := 32
while ((i > 0) AND ((windowSize MODULUS i) ≠ 0))
BEGIN
    shift_amount := shift_amount times 2
    i := the integer truncation (floor) of (i divided by 2)
END
shift_amount := shift_amount MODULUS 32
```

hash\_value<sub>i</sub> is an unsigned 32-bit integer that contains a calculated hash value. By definition, hash\_value<sub>-1</sub> is zero. Computing the H3 value for the windowSize byte ending at byte i depends on hash\_value<sub>i-1</sub>. For the purposes of H3, all data bytes before the beginning of the *file* are treated as having a value of 0.

trailingEdgeData and leadingEdgeData contain the data bytes (unsigned 8-bit integers) that are at the trailing edge and leading edge in a sequence of windowSize bytes. These data bytes become indices into the H3 lookup table for the purposes of the hash calculation.



To add leadingEdgeData to the hash value and remove trailingEdgeData (that is, to compute the H3 value of the windowSize bytes ending with the leading edge), compute:

```
hash_valuei :=
    rotate_bits_left(
        hash_valuei-1 XOR
        H3 lookup table[trailingEdgeData] XOR
        H3 lookupTable[leadingEdgeData],
        shift_amount
    )
```

This becomes the new hash\_value for moving the window one byte farther along.

Note that when processing near the beginning of the *file* (when the leading edge is less than the **hash window**), the trailing edge will actually be less than zero (before the beginning of the *file*). In this case, H3 considers this non-existent data to be all zeros.

The pseudocode below shows how hash\_value is computed for each offset i.

```
hash_value-1 := 0
FOR i = 0 to min(windowSize-1, Length of the file - 1)
    hash_valuei :=
        rotate_bits_left(
            hash_valuei-1 XOR
            H3 lookup table[0] XOR
            H3 lookup table[File[i]], shift_amount)
FOR i = windowSize to Length of File - 1
BEGIN
    trailingEdgeData := File[i - windowSize]
    leadingEdgeData := File[i]
    hash_valuei :=
        rotate_bits_left(
            hash_valuei-1 XOR
            H3 lookup table[trailingEdgeData] XOR
            H3 lookup table[leadingEdgeData],
            shift_amount)
END
```

For an example of H3 hash calculation, see section [4.2](#).

### 3.1.5.1.2 Finding Chunk Boundaries

Given a file *F* of length *n* consisting of bytes  $b_0 \dots b_{n-1}$  and parameters windowSize and **horizon**, **RDC** finds the **chunk** boundaries. windowSize **MUST** be an integer that is at least 2 and no more than 96. **Horizon** **MUST** be an integer that is at least 128 and less than 16,384. Recall that windowSize and **horizon** are inputs to the Remote Differential Compression Protocol, and **MUST** be negotiated between the two parties participating in a transfer using **RDC**.

A byte  $b_i$  is a **local maximum** if  $I > \text{horizon}$  and for all  $j \neq I$  where  $I - \text{horizon} \leq j \leq I + \text{horizon}$ , the H3 hash value after adding  $b_i$  is greater than that after adding any  $b_j$ .

To determine the **chunks** of *F*, define the first **chunk** to start with  $b_0$ . Work through each consecutive byte from  $b_1$  to  $b_{n-1}$ . A **chunk** starts at a byte that is a **local maximum** or that is 65,535 bytes beyond the last byte that started a **chunk**.

Thus, the following is a recursive definition of **chunk** boundaries:

```
File position 0 is a chunk boundary
File position n > 0 is a chunk boundary if:
    FORALL k in { n-horizon .. n+horizon } \ { n }
        hash_valuen > hash_valuek
    or    n - 65,535 = 0 and
        n - 65,535 is a chunk boundary and
        FORALL k in { n - 65,534 .. n - 1 }
            k is not a chunk boundary.
```

**Note** The "\" operator means exclusion; so in this construct, it means all values in the range except n.

Define boundary<sub>i</sub> to be the I<sup>th</sup> **chunk** boundary.

### 3.1.5.2 Signature Computation

There are two fields in a **chunk signature**: hash and block length. Given a **chunk**, the hash MUST be the **MD4** hash (as specified in [\[RFC1320\]](#)) of the data in the **chunk**, and the block length MUST be the number of bytes in the **chunk**. Because the block length is an unsigned 16-bit integer, all **chunks** MUST be less than or equal to 2<sup>16</sup>-1 bytes in length. Recall that the **signatures** comprise the data in the **signature file**, which is transmitted as part of using **RDC**.

Thus, the set of **signatures** is specified by:

```
FOR each chunk consisting of bytes from
    boundaryi to boundaryi+1-1:
    BEGIN

        Signature Hashi := MD4 of File[boundaryi] ... File[boundaryi+1-1]
        Signature block Lengthi := boundaryi+1 - boundaryi
    END
```

### 3.1.5.3 Recursion

Just as **RDC** can be used to determine the differences between the two original *files*, **RDC** can first be applied to determine the differences between the two signature *files*, or between the signature *files* of the signature *files*, and so on. This is called recursion.

For an example of recursion, see section [4.4](#).

#### 3.1.5.3.1 Recursion Depth

An implementation MUST support a recursion depth of at least eight levels. The depth of recursion that an application uses depends on the size of the signature *file* being transferred versus how many **chunks** of the signature *file* need to be transferred for each **recursion level**. The application must determine when bandwidth would be better utilized by just sending a bigger signature *file* to avoid another round of signature data transfer. [<3>](#)

The determination of recursion depth is application specific, and is not addressed in this document. [<4>](#)

### 3.1.5.4 Similarity

The effectiveness of data replication using **RDC** techniques depends to a large degree on the **seed files** that can be found on the **client**. If the **RDC** scenario is simple, such as the synchronization of a *file* that has been replicated recently, the choice of **seed file** can be as simple as the *file* that is being synchronized. If the **RDC** scenario is more complicated, such as the replication of a directory of *files*, it is possible that *files* have been added to the **server** that do not exist on the **client**, in which case there is no simple choice of **seed files**.

To help choose **seed files** under the circumstances outlined above, **similarity data** for new *files* on the **server** is calculated and sent to the **client**. The **similarity data** is used on the **client** to find existing *files* that are similar to the new **server files**. The existing **client files** can then become the **seed files** for an **RDC** replication of the new **server files**, making the transfer of the new *files* more efficient.

**Similarity data** MAY appear in protocols that use **RDC**, but it has no other effect on the protocol itself. Recall that **similarity data** MAY be used for identifying a **seed file** on the **client**.[<5>](#5)

#### 3.1.5.4.1 Similarity Data Calculation

Given a **file** *F* to calculate the **similarity data**, a 16-byte array is needed to store intermediate **MD4** digests. The data construct is called a digest for the purpose of this discussion. The calculation of **similarity data** for a **file** is expressed using the following pseudocode.

```
Define Digest as unsigned char[16]
Digest md4Results
Digest sData[16] = [0xff, 0xff, ..., 0xff]
unsigned char tempBuffer[17]
FOR each RDC Signature of a File
BEGIN
    Copy the RDC Signature data into tempBuffer
    FOR index = 0 to 15
    BEGIN
        tempBuffer[16] := index + 1
        Compute an MD4 digest for the data in tempBuffer,
        put the results in md4Results
        IF md4Results < sData[index]
            Copy the MD4 digest from md4Results to sData[index]
    END
END
END
```

The less-than comparison "*md4Results < sData[index]*" is a byte-by-byte comparison. For example, given *A* and *B* (two digests), the digests are considered as arrays of 16 unsigned 8-bit integers, where *A*<sub>0</sub> is the first byte and *A*<sub>15</sub> is the last byte of *A*. *A* < *B* is true if the first *A*<sub>*i*</sub> that is different than *B*<sub>*i*</sub> is less than *B*<sub>*i*</sub> for values of *i* in 0 to 15.

Once all **RDC signatures** for a **file** have been processed, the **similarity data** is extracted from the array of temporary digest constructs (named *sData* in the pseudocode shown above). The **similarity data** is constructed by taking the 8<sup>th</sup> byte from each of the 16 digests computed above and masking off the top 2 bits. This is shown in the following pseudocode.

```
unsigned char similarity[16]
FOR index = 0 to 15
    similarity[index] := sData[index, 7] & 0x3F
```

The data in similarity, shown in the pseudocode above, is the **similarity data** for the **file**.

Each trait of **similarity data** MUST be a value from 0 to 63 inclusive.

An implementation that does not compute **similarity data** MUST fill in all traits as zero.

#### 3.1.5.4.2 Finding Seed Files

Using the **similarity data** that has been calculated for *files* on the **client**, it may be possible to find **RDC seed files** for *files* that have been added to the **server** but not to the **client**. **Similarity data** consists of 16 bytes of data called **similarity traits**.

When the **server** has a new *file* that needs to be replicated on the **client**, the application on the **server** can send the **similarity data** of the new *file* to the **client**. The application on the **client** compares the **similarity traits** of the new *file* to the **similarity traits** of each of the **client's** existing *files*, counting the **similarity traits** that are the same (that is, that match). The application can then determine what of the existing *files* are used as seed-based on the number of **similarity trait** matches; for example, based on a threshold or a majority scheme. The choice of what scheme is used is implementation specific. [<6>](#)

Note that **similarity traits** are compared on a one-to-one basis so that there are at most 16 comparisons for each **client file**. That is, the first **similarity trait** of the new *file* is compared to the first **similarity trait** of a **client file**, the second **similarity trait** is compared to the second **similarity trait**, and so on.

Any number of **client files** can be used as **seed files** for an **RDC** operation. **Client files** with the greatest number of **similarity traits** that match the **similarity traits** of the new **server file** are generally the best candidates.

#### 3.1.5.5 Generating the Target File

To generate a **target file**, the protocol using **RDC** MUST obtain a **signature file** from the **server**, and MUST select one or more **seed files** on the **client**. The **seed files** can be selected in any vendor-specific manner, including using **similarity data** (see section [3.1.5.4](#)).

The **client** then reconstructs the **target file** by obtaining the necessary **chunks** from the **source file** and combining them with existing **chunks** from the **seed files**. It is the responsibility of the protocol using **RDC** to transport the **signature file** and any **chunks**.

The following pseudocode specifies the process of generating the **target file**. Note that each FOR loop iteration is independent of the others, and so may be executed concurrently.

```
Given n Source Signatures, SouSig0 .. SouSign-1,
    and m Seed Signatures, SeedSig0 .. SeedSigm-1
where each Signature has fields len and hash.
Produce Target File T, with bytes T0 .. Tp
where p is the sum of SouSigi.len for all i in 0 .. n.
FOR i = 0 to n-1
BEGIN
    offset := sum SouSig0 to SouSigi.
    IF there exists j < m such that SeedSigj.hash = SouSigi.hash
        and SeedSigj.len = SouSigi.len
        Toffset .. Toffset+SouSigi.len := the bytes from Chunk j
        of the seed.
    ELSE
        BEGIN
```

```
Fetch Chunk i from the server
    (how depends on the protocol using RDC).
Toffset .. Toffset+SouSigi.len := bytes from Chunk i
                                of the Source.
END
END
```

### **3.1.6 Timer Events**

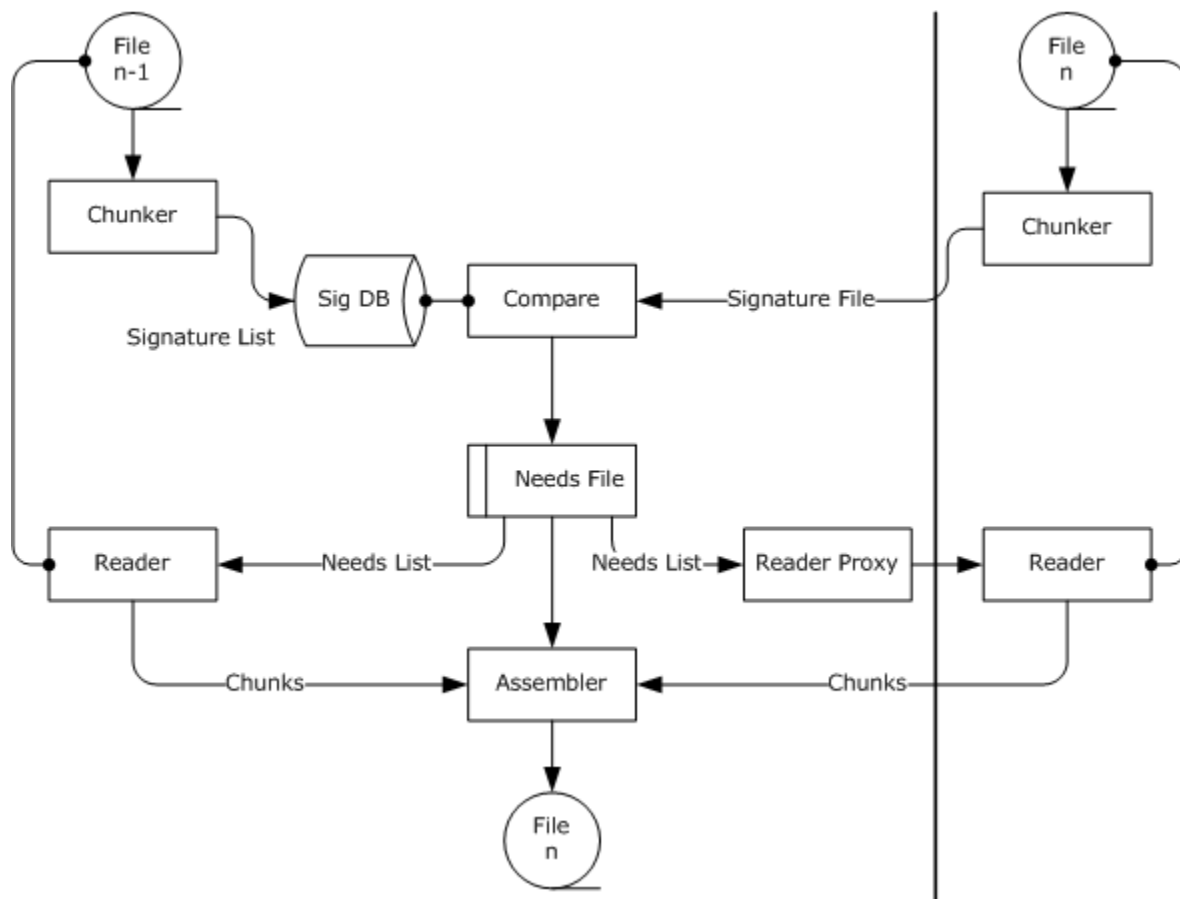
None.

### **3.1.7 Other Local Events**

None.

## 4 Protocol Examples

### 4.1 Example System Architecture



**Figure 1: Data flow of RDC in an application**

The figure above shows the data flow of a possible usage of the Remote Differential Compression Protocol in an application. Note that there are other possible ways to implement **RDC** in an application.

The following terms, in addition to glossary terms (see section [1.1](#)), are used in this example.

**Assembler:** A function that constructs the **target file** using three inputs: needs lists, source **chunks**, and seed **chunks**.

**Compare:** A function that compares the **signatures** of the **seed files** and **source files**. After performing this comparison, the Compare function produces a list of needs.

**Needs:** A description of a block of data from either the **source file** or the **seed file** that is necessary to construct the **target file**.

**Needs List:** A list of needs in some application-defined format.

**Reader:** A function that reads **chunks** from a **seed file** or a **source file** as determined by the needs list.

**Reader Proxy:** A function that communicates with the reader on the **server**.

The vertical line represents the network separation between two machines. The **file** to be transferred exists on the machine on the right (the **server** for this example); the **file** is to be transferred to the machine on the left (the **client** for this example).

**Chunks** of both the **seed data** and the corresponding **source data** are examined, and a **signature** is generated for each **chunk**. The **signatures** generated on the **client** (that is, the seed signatures) can be stored using any mechanism. The **signatures** generated on the **server** (that is, the source signatures) are sent to the **client** in the form of a **signature file**.

The **client** examines the source **signatures**. For each source **signature**, the **client** tries to find a matching seed **signature**. If a matching seed **signature** is found, the **client** already has the corresponding **chunk** of data and does not need to download it. If no matching seed **signature** can be found for a particular source **signature**, the **client** must download the corresponding **chunk** of data from the **server**.

When the **client** has all of the data **chunks** (those it already had, and those it downloaded from the **server**), the **client** assembles the **chunks** in the order that corresponds to the **signature file** that was received from the **server**.

For more information on the high-level aspects of **RDC**, see [\[MSDN-RDCAPI\]](#).

## 4.2 H3

This section gives an example of computing the H3 hashes of a sequence of 11 bytes of data with a windowSize of 4.

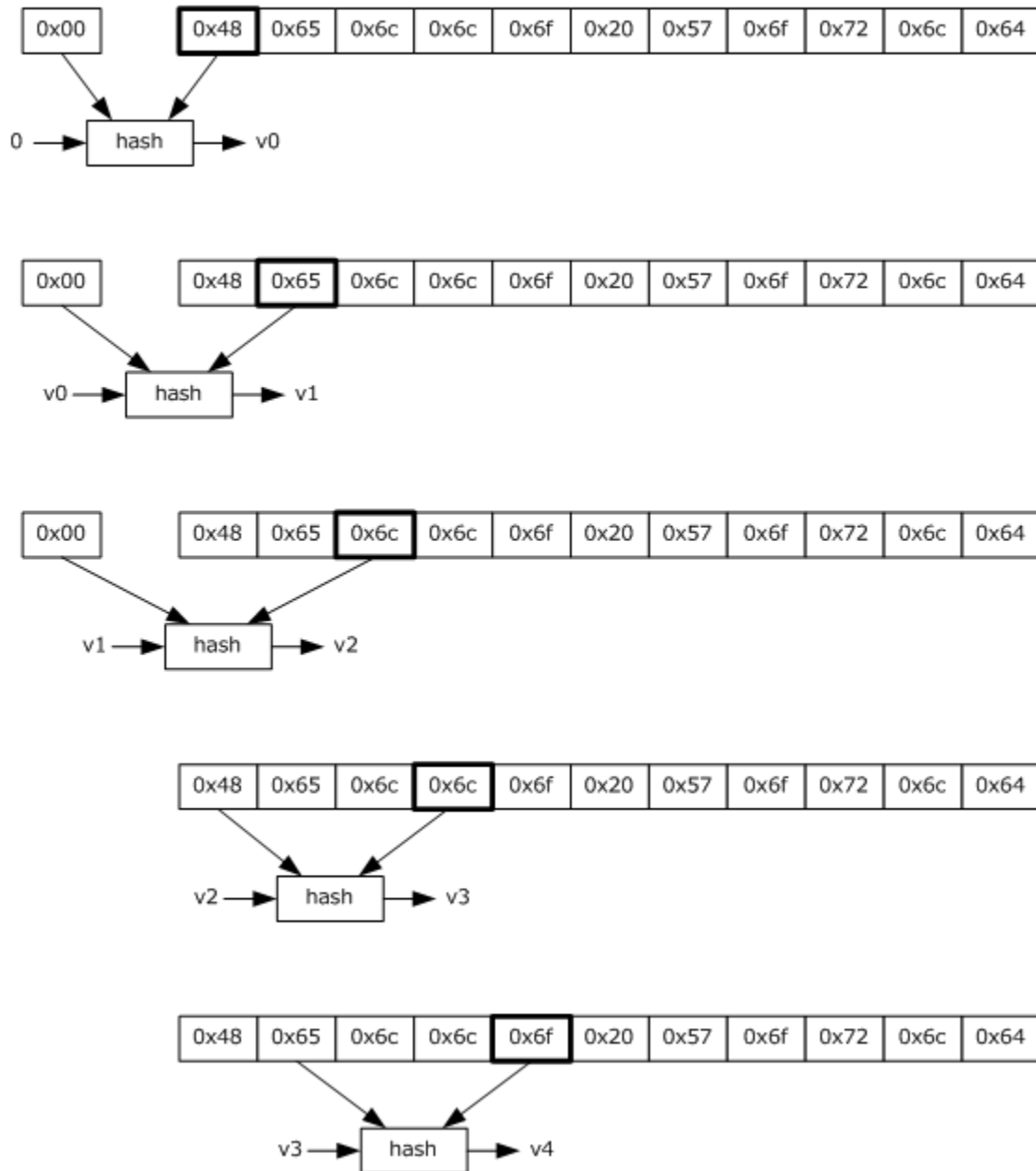
First, H3 must determine the appropriate shift\_amount for a four-byte windowSize. Applying the algorithm in section [3.1.5.1.1](#) yields a shift\_amount of eight.

hash\_value is initialized to 0, and the H3 algorithm starts at the first data byte. Recall that for the purposes of H3, all data bytes before the beginning of the **file** are treated as having 0 value. Therefore, in the example that follows, this is rotate\_bits\_left(0 XOR H3 Table[0] XOR H3 Table[0x48],8). Looking into the H3 table yields H3 Table[0] = 0x5e3f7c48 and H3 Table[0x48] = 0x3d519a77. Computing the XOR yields 0x636ee63f, and rotating left 8 bits yields 0x6ee63f63, which is the first H3 value, v0.

To compute v1, repeat the procedure using v0 as the initial hash\_value; that is, rotate\_bits\_left(0x6ee63f63 XOR H3 Table[0] XOR H3 Table[0x65],8). H3 Table[0] = 0x5e3f7c48 and H3 Table[0x65] = 0x824fdb8e, so the result of the XOR is 0xb29698c3. Rotating yields v1 = 0x9698c3b2.

Because of the way shift\_amount is computed (windowSize \* shift\_amount), MODULUS 32 = 0. Therefore, when a byte is at the trailing edge of the window, the XOR with its corresponding table value is in the same position as when the table value was XORed in when it was at the leading edge. Furthermore, for all a, a XOR a = 0, so the second XOR cancels out the effect of the first one. Therefore, the H3 value for a window does not depend on any bytes outside the window, and H3 is a **hash function**.

The hash values v0, v1, and so on represent the data bytes that are highlighted.

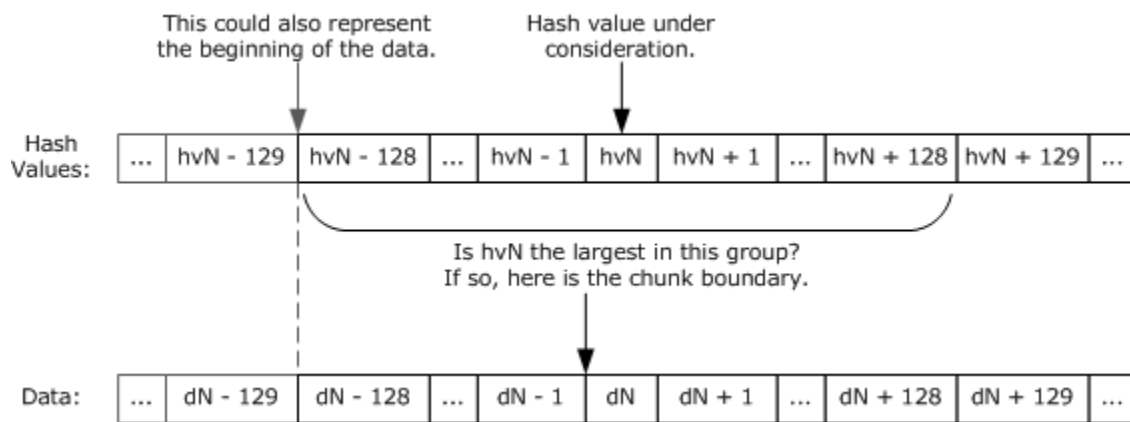


**Figure 2: How `shift_amount` is computed**

### 4.3 FilterMax

The relationship between **local maximum** and **horizon** is illustrated in the following figure, which assumes a **horizon** size of 128.

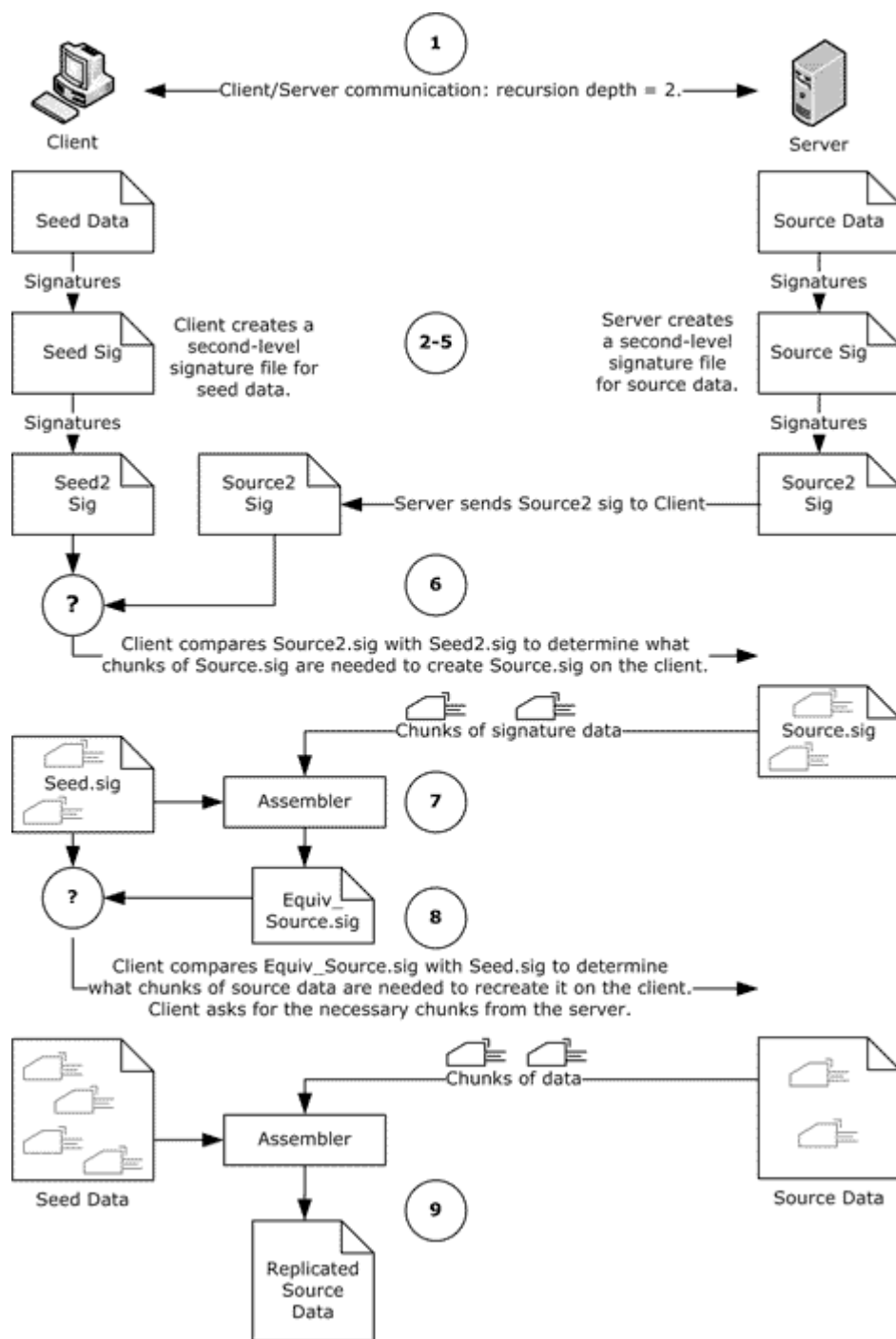




**Figure 3: Relationship between local maximum and horizon**

In the diagram above, consider if  $hvN$  is the largest in the indicated range of values. Then it follows that none of the other values in this range may be a **local maximum** (because they are smaller than  $hvN$ ). Therefore, local maxima must be separated by at least **horizon** bytes.

## 4.4 Sample Recursive Client Transfer



**Figure 4: Recursion-depth calculation**

1. The **client** and **server** determine that a recursion depth of 2 is appropriate.

Notes:

- The **RDC** library allows the application to choose the recursion depth arbitrarily. Choosing an optimum recursion depth is difficult because many factors are involved, including the available network bandwidth and network latency, the speed and load of the disk storage systems on the **server** and **client** machines, and available CPU time for computing **signatures**, if necessary. For an example of recursion-depth calculation, see [MS-FRS2] section [3.2.1.5](#).
  - The terms **client** and **server** in this discussion refer only to the computers' roles in the **RDC** scenario, not to their operating systems.
  - The method used by the **client** and **server** to agree on recursion depth is application specific.
2. The **client** generates **signatures** for the **seed data** and stores them in a *file* called seed.sig.
  3. The **client** generates **signatures** for seed.sig and stores them in a *file* called seed2.sig.
  4. The **server** generates **signatures** for the source data and stores them in a *file* called source.sig.
  5. The **server** generates **signatures** for source.sig and stores them in a *file* called source2.sig. The **server** then sends source2.sig to the **client**.
  6. The **client** examines the **signatures** in source2.sig, comparing them to the **signatures** in seed2.sig to determine the **chunks** of source.sig it needs.
  7. With source2.sig as a guide, the **client** creates a first-level **signature file** that is identical to source.sig (called equiv\_source.sig for this example). Instead of transferring the entire source.sig *file* to the **client**, the much smaller source2.sig *file* is transferred along with the few pieces of source.sig that are needed.
  8. The **client** examines the **signatures** in equiv\_source.sig, comparing them to the **signatures** in seed.sig to determine the **chunks** of the **source data** it needs.
  9. With equiv\_source.sig as a guide, the **client** recreates the **source data** using normal **RDC** techniques.

Using the concepts described above, it may be possible to use a smaller amount of bandwidth to transfer the **source data** across the network. If, for example, the **source data** is approximately 9 gigabytes, the first-level **signature file** will be approximately 92 megabytes, but the second-level **signature file** will be only about 944 kilobytes.

## 4.5 Sample Input and Generated Signature File

To test an implementation, the following example of a **source file** (the full text of rfc1320.txt) is used, and the resultant **signature file** is generated using windowSize 16 and **horizon** 512.

File: rfc1320.txt displayed in hexadecimal format, 16 bytes per line.

```
00000000: 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 4e 65 74 77 6f 72
00000010: 6b 20 57 6f 72 6b 69 6e 67 20 47 72 6f 75 70 20
00000020: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00000030: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00000040: 20 20 20 20 20 20 20 20 20 52 2e 20 52 69 76 65
00000050: 73 74 0d 0a 52 65 71 75 65 73 74 20 66 6f 72 20
00000060: 43 6f 6d 6d 65 6e 74 73 3a 20 31 33 32 30 20 20
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00007290: 5f 43 4f 55 4e 54 3b 20 69 2b 2b 29 0d 0a 20 20
000072a0: 20 20 4d 44 55 70 64 61 74 65 20 28 26 63 6f 6e
000072b0: 74 65 78 74 2c 20 62 6c 6f 63 6b 2c 20 54 45 53
000072c0: 54 5f 42 4c 4f 43 4b 5f 4c 45 4e 29 3b 0d 0a 20
000072d0: 20 4d 44 46 69 6e 61 6c 20 28 64 69 67 65 73 74
000072e0: 2c 20 26 63 6f 6e 74 65 78 74 29 3b 0d 0a 0d 0a
000072f0: 20 20 2f 2a 20 53 74 6f 70 20 74 69 6d 65 72 20
00007300: 2a 2f 0d 0a 20 20 74 69 6d 65 20 28 26 65 6e 64
00007310: 54 69 6d 65 29 3b 0d 0a 0d 0a 20 20 70 72 69 6e
00007320: 74 66 20 28 22 20 64 6f 6e 65 5c 6e 22 29 3b 0d
00007330: 0a 20 20 70 72 69 6e 74 66 20 28 22 44 69 67 65
00007340: 73 74 20 3d 20 22 29 3b 0d 0a 20 20 4d 44 50 72
00007350: 69 6e 74 20 28 64 69 67 65 73 74 29 3b 0d 0a 0d
00007360: 0a 0d 0a 0d 0a 52 69 76 65 73 74 20 20 20 20 20
00007370: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00007380: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00007390: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000073a0: 20 20 20 20 5b 50 61 67 65 20 31 37 5d 0d 0a 0c
000073b0: 0d 0a 52 46 43 20 31 33 32 30 20 20 20 20 20 20
000073c0: 20 20 20 20 20 20 20 20 4d 44 34 20 4d 65 73 73
000073d0: 61 67 65 2d 44 69 67 65 73 74 20 41 6c 67 6f 72
000073e0: 69 74 68 6d 20 20 20 20 20 20 20 20 20 20 20 20
000073f0: 41 70 72 69 6c 20 31 39 39 32 0d 0a 0d 0a 0d 0a
00007400: 20 20 70 72 69 6e 74 66 20 28 22 5c 6e 54 69 6d
00007410: 65 20 3d 20 25 6c 64 20 73 65 63 6f 6e 64 73 5c
00007420: 6e 22 2c 20 28 6c 6f 6e 67 29 28 65 6e 64 54 69
00007430: 6d 65 2d 73 74 61 72 74 54 69 6d 65 29 29 3b 0d
00007440: 0a 20 20 70 72 69 6e 74 66 0d 0a 20 20 20 20 28
00007450: 22 53 70 65 65 64 20 3d 20 25 6c 64 20 62 79 74
00007460: 65 73 2f 73 65 63 6f 6e 64 5c 6e 22 2c 0d 0a 20
00007470: 20 20 20 20 28 6c 6f 6e 67 29 54 45 53 54 5f 42
00007480: 4c 4f 43 4b 5f 4c 45 4e 20 2a 20 28 6c 6f 6e 67

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00007490: 29 54 45 53 54 5f 42 4c 4f 43 4b 5f 43 4f 55 4e
000074a0: 54 2f 28 65 6e 64 54 69 6d 65 2d 73 74 61 72 74
000074b0: 54 69 6d 65 29 29 3b 0d 0a 7d 0d 0a 0d 0a 2f 2a
000074c0: 20 44 69 67 65 73 74 73 20 61 20 72 65 66 65 72
000074d0: 65 6e 63 65 20 73 75 69 74 65 20 6f 66 20 73 74
000074e0: 72 69 6e 67 73 20 61 6e 64 20 70 72 69 6e 74 73
000074f0: 20 74 68 65 20 72 65 73 75 6c 74 73 2e 0d 0a 20
00007500: 2a 2f 0d 0a 73 74 61 74 69 63 20 76 6f 69 64 20
00007510: 4d 44 54 65 73 74 53 75 69 74 65 20 28 29 0d 0a
00007520: 7b 0d 0a 20 20 70 72 69 6e 74 66 20 28 22 4d 44
00007530: 25 64 20 74 65 73 74 20 73 75 69 74 65 3a 5c 6e
00007540: 22 2c 20 4d 44 29 3b 0d 0a 0d 0a 20 20 4d 44 53
00007550: 74 72 69 6e 67 20 28 22 22 29 3b 0d 0a 20 20 4d
00007560: 44 53 74 72 69 6e 67 20 28 22 61 22 29 3b 0d 0a
00007570: 20 20 4d 44 53 74 72 69 6e 67 20 28 22 61 62 63
00007580: 22 29 3b 0d 0a 20 20 4d 44 53 74 72 69 6e 67 20
00007590: 28 22 6d 65 73 73 61 67 65 20 64 69 67 65 73 74
000075a0: 22 29 3b 0d 0a 20 20 4d 44 53 74 72 69 6e 67 20
000075b0: 28 22 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e
000075c0: 6f 70 71 72 73 74 75 76 77 78 79 7a 22 29 3b 0d
000075d0: 0a 20 20 4d 44 53 74 72 69 6e 67 0d 0a 20 20 20
000075e0: 20 28 22 41 42 43 44 45 46 47 48 49 4a 4b 4c 4d
000075f0: 4e 4f 50 51 52 53 54 55 56 57 58 59 5a 61 62 63
00007600: 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 72 73
00007610: 74 75 76 77 78 79 7a 30 31 32 33 34 35 36 37 38
00007620: 39 22 29 3b 0d 0a 20 20 4d 44 53 74 72 69 6e 67
00007630: 0d 0a 0d 0a 20 20 20 20 28 22 31 32 33 34 35 36
00007640: 37 38 39 30 31 32 33 34 35 36 37 38 39 30 31 32
00007650: 33 34 35 36 37 38 39 30 31 32 33 34 35 36 37 38
00007660: 39 30 5c 0d 0a 31 32 33 34 35 36 37 38 39 30 31
00007670: 32 33 34 35 36 37 38 39 30 31 32 33 34 35 36 37
00007680: 38 39 30 31 32 33 34 35 36 37 38 39 30 22 29 3b
00007690: 0d 0a 7d 0d 0a 0d 0a 2f 2a 20 44 69 67 65 73 74
000076a0: 73 20 61 20 66 69 6c 65 20 61 6e 64 20 70 72 69
000076b0: 6e 74 73 20 74 68 65 20 72 65 73 75 6c 74 2e 0d
000076c0: 0a 20 2a 2f 0d 0a 73 74 61 74 69 63 20 76 6f 69
000076d0: 64 20 4d 44 46 69 6c 65 20 28 66 69 6c 65 6e 61
000076e0: 6d 65 29 0d 0a 63 68 61 72 20 2a 66 69 6c 65 6e
000076f0: 61 6d 65 3b 0d 0a 7b 0d 0a 20 20 46 49 4c 45 20
00007700: 2a 66 69 6c 65 3b 0d 0a 20 20 4d 44 5f 43 54 58
00007710: 20 63 6f 6e 74 65 78 74 3b 0d 0a 20 20 69 6e 74
00007720: 20 6c 65 6e 3b 0d 0a 20 20 75 6e 73 69 67 6e 65
00007730: 64 20 63 68 61 72 20 62 75 66 66 65 72 5b 31 30
00007740: 32 34 5d 2c 20 64 69 67 65 73 74 5b 31 36 5d 3b
00007750: 0d 0a 0d 0a 20 20 69 66 20 28 28 66 69 6c 65 20
00007760: 3d 20 66 6f 70 65 6e 20 28 66 69 6c 65 6e 61 6d
00007770: 65 2c 20 22 72 62 22 29 29 20 3d 3d 20 4e 55 4c
00007780: 4c 29 0d 0a 20 20 20 20 70 72 69 6e 74 66 20 28
00007790: 22 25 73 20 63 61 6e 27 74 20 62 65 20 6f 70 65
000077a0: 6e 65 64 5c 6e 22 2c 20 66 69 6c 65 6e 61 6d 65
000077b0: 29 3b 0d 0a 0d 0a 20 20 65 6c 73 65 20 7b 0d 0a
000077c0: 20 20 20 20 4d 44 49 6e 69 74 20 28 26 63 6f 6e
000077d0: 74 65 78 74 29 3b 0d 0a 20 20 20 20 77 68 69 6c
000077e0: 65 20 28 6c 65 6e 20 3d 20 66 72 65 61 64 20 28
000077f0: 62 75 66 66 65 72 2c 20 31 2c 20 31 30 32 34 2c
00007800: 20 66 69 6c 65 29 29 0d 0a 20 20 20 20 20 20 20 4d
00007810: 44 55 70 64 61 74 65 20 28 26 63 6f 6e 74 65 78
00007820: 74 2c 20 62 75 66 66 65 72 2c 20 6c 65 6e 29 3b

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00007830: 0d 0a 20 20 20 20 4d 44 46 69 6e 61 6c 20 28 64
00007840: 69 67 65 73 74 2c 20 26 63 6f 6e 74 65 78 74 29
00007850: 3b 0d 0a 0d 0a 20 20 20 20 66 63 6c 6f 73 65 20
00007860: 28 66 69 6c 65 29 3b 0d 0a 0d 0a 20 20 20 20 70
00007870: 72 69 6e 74 66 20 28 22 4d 44 25 64 20 28 25 73
00007880: 29 20 3d 20 22 2c 20 4d 44 2c 20 66 69 6c 65 6e
00007890: 61 6d 65 29 3b 0d 0a 20 20 20 20 4d 44 50 72 69
000078a0: 6e 74 20 28 64 69 67 65 73 74 29 3b 0d 0a 0d 0a
000078b0: 0d 0a 0d 0a 52 69 76 65 73 74 20 20 20 20 20 20
000078c0: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000078d0: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000078e0: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000078f0: 20 20 20 5b 50 61 67 65 20 31 38 5d 0d 0a 0c 0d
00007900: 0a 52 46 43 20 31 33 32 30 20 20 20 20 20 20 20
00007910: 20 20 20 20 20 20 20 4d 44 34 20 4d 65 73 73 61
00007920: 67 65 2d 44 69 67 65 73 74 20 41 6c 67 6f 72 69
00007930: 74 68 6d 20 20 20 20 20 20 20 20 20 20 20 20 41
00007940: 70 72 69 6c 20 31 39 39 32 0d 0a 0d 0a 0d 0a 20
00007950: 20 20 20 70 72 69 6e 74 66 20 28 22 5c 6e 22 29
00007960: 3b 0d 0a 20 20 7d 0d 0a 7d 0d 0a 0d 0a 2f 2a 20
00007970: 44 69 67 65 73 74 73 20 74 68 65 20 73 74 61 6e
00007980: 64 61 72 64 20 69 6e 70 75 74 20 61 6e 64 20 70
00007990: 72 69 6e 74 73 20 74 68 65 20 72 65 73 75 6c 74
000079a0: 2e 0d 0a 20 2a 2f 0d 0a 73 74 61 74 69 63 20 76
000079b0: 6f 69 64 20 4d 44 46 69 6c 74 65 72 20 28 29 0d
000079c0: 0a 7b 0d 0a 20 20 4d 44 5f 43 54 58 20 63 6f 6e
000079d0: 74 65 78 74 3b 0d 0a 20 20 69 6e 74 20 6c 65 6e
000079e0: 3b 0d 0a 20 20 75 6e 73 69 67 6e 65 64 20 63 68
000079f0: 61 72 20 62 75 66 66 65 72 5b 31 36 5d 2c 20 64
00007a00: 69 67 65 73 74 5b 31 36 5d 3b 0d 0a 0d 0a 20 20
00007a10: 4d 44 49 6e 69 74 20 28 26 63 6f 6e 74 65 78 74
00007a20: 29 3b 0d 0a 20 20 77 68 69 6c 65 20 28 6c 65 6e
00007a30: 20 3d 20 66 72 65 61 64 20 28 62 75 66 66 65 72
00007a40: 2c 20 31 2c 20 31 36 2c 20 73 74 64 69 6e 29 29
00007a50: 0d 0a 20 20 20 20 4d 44 55 70 64 61 74 65 20 28
00007a60: 26 63 6f 6e 74 65 78 74 2c 20 62 75 66 66 65 72
00007a70: 2c 20 6c 65 6e 29 3b 0d 0a 20 20 4d 44 46 69 6e
00007a80: 61 6c 20 28 64 69 67 65 73 74 2c 20 26 63 6f 6e
00007a90: 74 65 78 74 29 3b 0d 0a 0d 0a 20 20 4d 44 50 72
00007aa0: 69 6e 74 20 28 64 69 67 65 73 74 29 3b 0d 0a 20
00007ab0: 20 70 72 69 6e 74 66 20 28 22 5c 6e 22 29 3b 0d
00007ac0: 0a 7d 0d 0a 0d 0a 2f 2a 20 50 72 69 6e 74 73 20
00007ad0: 61 20 6d 65 73 73 61 67 65 20 64 69 67 65 73 74
00007ae0: 20 69 6e 20 68 65 78 61 64 65 63 69 6d 61 6c 2e
00007af0: 0d 0a 20 2a 2f 0d 0a 73 74 61 74 69 63 20 76 6f
00007b00: 69 64 20 4d 44 50 72 69 6e 74 20 28 64 69 67 65
00007b10: 73 74 29 0d 0a 75 6e 73 69 67 6e 65 64 20 63 68
00007b20: 61 72 20 64 69 67 65 73 74 5b 31 36 5d 3b 0d 0a
00007b30: 0d 0a 7b 0d 0a 20 20 75 6e 73 69 67 6e 65 64 20
00007b40: 69 6e 74 20 69 3b 0d 0a 0d 0a 20 20 66 6f 72 20
00007b50: 28 69 20 3d 20 30 3b 20 69 20 3c 20 31 36 3b 20
00007b60: 69 2b 2b 29 0d 0a 20 20 20 20 70 72 69 6e 74 66
00007b70: 20 28 22 25 30 32 78 22 2c 20 64 69 67 65 73 74
00007b80: 5b 69 5d 29 3b 0d 0a 7d 0d 0a 0d 0a 41 2e 35 20
00007b90: 54 65 73 74 20 73 75 69 74 65 0d 0a 0d 0a 20 20
00007ba0: 20 54 68 65 20 4d 44 34 20 74 65 73 74 20 73 75
00007bb0: 69 74 65 20 28 64 72 69 76 65 72 20 6f 70 74 69
00007bc0: 6f 6e 20 22 2d 78 22 29 20 73 68 6f 75 6c 64 20

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00007bd0: 70 72 69 6e 74 20 74 68 65 20 66 6f 6c 6c 6f 77
00007be0: 69 6e 67 0d 0a 20 20 20 72 65 73 75 6c 74 73 3a
00007bf0: 0d 0a 0d 0a 4d 44 34 20 74 65 73 74 20 73 75 69
00007c00: 74 65 3a 0d 0a 4d 44 34 20 28 22 22 29 20 3d 20
00007c10: 33 31 64 36 63 66 65 30 64 31 36 61 65 39 33 31
00007c20: 62 37 33 63 35 39 64 37 65 30 63 30 38 39 63 30
00007c30: 0d 0a 4d 44 34 20 28 22 61 22 29 20 3d 20 62 64
00007c40: 65 35 32 63 62 33 31 64 65 33 33 65 34 36 32 34
00007c50: 35 65 30 35 66 62 64 62 64 36 66 62 32 34 0d 0a
00007c60: 4d 44 34 20 28 22 61 62 63 22 29 20 3d 20 61 34
00007c70: 34 38 30 31 37 61 61 66 32 31 64 38 35 32 35 66
00007c80: 63 31 30 61 65 38 37 61 61 36 37 32 39 64 0d 0a
00007c90: 4d 44 34 20 28 22 6d 65 73 73 61 67 65 20 64 69
00007ca0: 67 65 73 74 22 29 20 3d 20 64 39 31 33 30 61 38
00007cb0: 31 36 34 35 34 39 66 65 38 31 38 38 37 34 38 30
00007cc0: 36 65 31 63 37 30 31 34 62 0d 0a 4d 44 34 20 28
00007cd0: 22 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f
00007ce0: 70 71 72 73 74 75 76 77 78 79 7a 22 29 20 3d 20
00007cf0: 64 37 39 65 31 63 33 30 38 61 61 35 62 62 63 64
00007d00: 65 65 61 38 65 64 36 33 64 66 34 31 32 64 61 39
00007d10: 0d 0a 4d 44 34 20 28 22 41 42 43 44 45 46 47 48
00007d20: 49 4a 4b 4c 4d 4e 4f 50 51 52 53 54 55 56 57 58
00007d30: 59 5a 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e
00007d40: 6f 70 71 72 73 74 75 76 77 78 79 7a 30 31 32 33
00007d50: 34 35 36 37 38 39 22 29 20 3d 0d 0a 30 34 33 66
00007d60: 38 35 38 32 66 32 34 31 64 62 33 35 31 63 65 36
00007d70: 32 37 65 31 35 33 65 37 66 30 65 34 0d 0a 4d 44
00007d80: 34 20 28 22 31 32 33 34 35 36 37 38 39 30 31 32
00007d90: 33 34 35 36 37 38 39 30 31 32 33 34 35 36 37 38
00007da0: 39 30 31 32 33 34 35 36 37 38 39 30 31 32 33 34
00007db0: 35 36 37 38 39 30 31 32 33 34 35 36 37 38 39 30
00007dc0: 31 32 33 34 35 36 0d 0a 37 38 39 30 31 32 33 34
00007dd0: 35 36 37 38 39 30 22 29 20 3d 20 65 33 33 62 34
00007de0: 64 64 63 39 63 33 38 66 32 31 39 39 63 33 65 37
00007df0: 62 31 36 34 66 63 63 30 35 33 36 0d 0a 0d 0a 0d
00007e00: 0a 0d 0a 52 69 76 65 73 74 20 20 20 20 20 20 20
00007e10: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00007e20: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00007e30: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
00007e40: 20 20 5b 50 61 67 65 20 31 39 5d 0d 0a 0c 0d 0a
00007e50: 52 46 43 20 31 33 32 30 20 20 20 20 20 20 20 20
00007e60: 20 20 20 20 20 20 4d 44 34 20 4d 65 73 73 61 67
00007e70: 65 2d 44 69 67 65 73 74 20 41 6c 67 6f 72 69 74
00007e80: 68 6d 20 20 20 20 20 20 20 20 20 20 20 20 41 70
00007e90: 72 69 6c 20 31 39 39 32 0d 0a 0d 0a 0d 0a 53 65
00007ea0: 63 75 72 69 74 79 20 43 6f 6e 73 69 64 65 72 61
00007eb0: 74 69 6f 6e 73 0d 0a 0d 0a 20 20 20 54 68 65 20
00007ec0: 6c 65 76 65 6c 20 6f 66 20 73 65 63 75 72 69 74
00007ed0: 79 20 64 69 73 63 75 73 73 65 64 20 69 6e 20 74
00007ee0: 68 69 73 20 6d 65 6d 6f 20 69 73 20 63 6f 6e 73
00007ef0: 69 64 65 72 65 64 20 74 6f 20 62 65 0d 0a 20 20
00007f00: 20 73 75 66 66 69 63 69 65 6e 74 20 66 6f 72 20
00007f10: 69 6d 70 6c 65 6d 65 6e 74 69 6e 67 20 6d 6f 64
00007f20: 65 72 61 74 65 20 73 65 63 75 72 69 74 79 20 68
00007f30: 79 62 72 69 64 20 64 69 67 69 74 61 6c 2d 0d 0a
00007f40: 20 20 20 73 69 67 6e 61 74 75 72 65 20 73 63 68
00007f50: 65 6d 65 73 20 62 61 73 65 64 20 6f 6e 20 4d 44
00007f60: 34 20 61 6e 64 20 61 20 70 75 62 6c 69 63 2d 6b

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00007f70: 65 79 20 63 72 79 70 74 6f 73 79 73 74 65 6d 2e
00007f80: 20 57 65 20 64 6f 0d 0a 20 20 20 6e 6f 74 20 6b
00007f90: 6e 6f 77 20 6f 66 20 61 6e 79 20 72 65 61 73 6f
00007fa0: 6e 20 74 68 61 74 20 4d 44 34 20 77 6f 75 6c 64
00007fb0: 20 6e 6f 74 20 62 65 20 73 75 66 66 69 63 69 65
00007fc0: 6e 74 20 66 6f 72 0d 0a 20 20 20 69 6d 70 6c 65
00007fd0: 6d 65 6e 74 69 6e 67 20 76 65 72 79 20 68 69 67
00007fe0: 68 20 73 65 63 75 72 69 74 79 20 64 69 67 69 74
00007ff0: 61 6c 2d 73 69 67 6e 61 74 75 72 65 20 73 63 68
00008000: 65 6d 65 73 2c 20 62 75 74 0d 0a 20 20 20 62 65
00008010: 63 61 75 73 65 20 4d 44 34 20 77 61 73 20 64 65
00008020: 73 69 67 6e 65 64 20 74 6f 20 62 65 20 65 78 63
00008030: 65 70 74 69 6f 6e 61 6c 6c 79 20 66 61 73 74 2c
00008040: 20 69 74 20 69 73 20 22 61 74 20 74 68 65 0d 0a
00008050: 20 20 20 65 64 67 65 22 20 69 6e 20 74 65 72 6d
00008060: 73 20 6f 66 20 72 69 73 6b 69 6e 67 20 73 75 63
00008070: 63 65 73 73 66 75 6c 20 63 72 79 70 74 61 6e 61
00008080: 6c 79 74 69 63 20 61 74 74 61 63 6b 2e 20 41 66
00008090: 74 65 72 0d 0a 20 20 20 66 75 72 74 68 65 72 20
000080a0: 63 72 69 74 69 63 61 6c 20 72 65 76 69 65 77 2c
000080b0: 20 69 74 20 6d 61 79 20 62 65 20 61 70 70 72 6f
000080c0: 70 72 69 61 74 65 20 74 6f 20 63 6f 6e 73 69 64
000080d0: 65 72 20 4d 44 34 20 66 6f 72 0d 0a 20 20 20 76
000080e0: 65 72 79 20 68 69 67 68 20 73 65 63 75 72 69 74
000080f0: 79 20 61 70 70 6c 69 63 61 74 69 6f 6e 73 2e 20
00008100: 46 6f 72 20 76 65 72 79 20 68 69 67 68 20 73 65
00008110: 63 75 72 69 74 79 20 61 70 70 6c 69 63 61 74 69
00008120: 6f 6e 73 0d 0a 20 20 20 62 65 66 6f 72 65 20 74
00008130: 68 65 20 63 6f 6d 70 6c 65 74 69 6f 6e 20 6f 66
00008140: 20 74 68 61 74 20 72 65 76 69 65 77 2c 20 74 68
00008150: 65 20 4d 44 35 20 61 6c 67 6f 72 69 74 68 6d 20
00008160: 5b 34 5d 20 69 73 0d 0a 20 20 20 72 65 63 6f 6d
00008170: 6d 65 6e 64 65 64 2e 0d 0a 0d 0a 41 75 74 68 6f
00008180: 72 27 73 20 41 64 64 72 65 73 73 0d 0a 0d 0a 20
00008190: 20 20 52 6f 6e 61 6c 64 20 4c 2e 20 52 69 76 65
000081a0: 73 74 0d 0a 20 20 20 4d 61 73 73 61 63 68 75 73
000081b0: 65 74 74 73 20 49 6e 73 74 69 74 75 74 65 20 6f
000081c0: 66 20 54 65 63 68 6e 6f 6c 6f 67 79 0d 0a 20 20
000081d0: 20 4c 61 62 6f 72 61 74 6f 72 79 20 66 6f 72 20
000081e0: 43 6f 6d 70 75 74 65 72 20 53 63 69 65 6e 63 65
000081f0: 0d 0a 20 20 20 4e 45 34 33 2d 33 32 34 0d 0a 20
00008200: 20 20 35 34 35 20 54 65 63 68 6e 6f 6c 6f 67 79
00008210: 20 53 71 75 61 72 65 0d 0a 20 20 20 43 61 6d 62
00008220: 72 69 64 67 65 2c 20 4d 41 20 20 30 32 31 33 39
00008230: 2d 31 39 38 36 0d 0a 0d 0a 20 20 20 50 68 6f 6e
00008240: 65 3a 20 28 36 31 37 29 20 32 35 33 2d 35 38 38
00008250: 30 0d 0a 20 20 20 45 4d 61 69 6c 3a 20 72 69 76
00008260: 65 73 74 40 74 68 65 6f 72 79 2e 6c 63 73 2e 6d
00008270: 69 74 2e 65 64 75 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a
00008280: 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a
00008290: 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a
000082a0: 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 0d 0a 52 69 76 65
000082b0: 73 74 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000082c0: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000082d0: 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
000082e0: 20 20 20 20 20 20 20 20 20 20 20 20 5b 50 61 67 65
000082f0: 20 32 30 5d 0d 0a 0c

```

The resulting **signatures** and **similarity data** are shown in the following table. The **signatures** are shown in the format of one **signature** per line.

Block Length	MD4 Hash
3108	1d6406ded92381dc22cc36b8899b9fdd
2249	919c5d8510ff6387340a61f87b4a3956
6190	b4485ec7719b17df2543a2f711ce6eff
17389	3e752ed7d8f7d7c17fee487b2491a3e0
1301	1ac5c13f71f575ea8f332465baba2cb0
3290	a74b42809f62ed2aa022592b2bbf222c

The resulting **signature file** is shown in the following diagram.

**Note** Hexadecimal numbers that are bold represent the beginning of a **signature**.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0x18, 0x00, 0x00, 0x00																															
0x01, 0x00, 0x01, 0x00																															
0x01, 0x00, 0x01, 0x00																															
0																															
0x01, 0x00, 0x00, 0x00																															
0																															
0x1d, 0x64, 0x06, 0xde																															
0xd9, 0x23, 0x81, 0xdc																															
0x22, 0xcc, 0x36, 0xb8																															
0x89, 0x9b, 0x9f, 0xdd																															
0x24, 0x0C, 0x91, 0x9c																															
0x5d, 0x85, 0x10, 0xff																															



0x63, 0x87, 0x34, 0x0a
0x61, 0xf8, 0x7b, 0x4a
0x39, 0x56, 0xC9, 0x08
<b>0xb4</b> , 0x48, 0x5e, 0xc7
0x71, 0x9b, 0x17, 0xdf
0x25, 0x43, 0xa2, 0xf7
0x11, 0xce, 0x6e, 0xff
0x2E, 0x18, <b>0x3e</b> , 0x75
0x2e, 0xd7, 0xd8, 0xf7
0xd7, 0xc1, 0x7f, 0xee
0x48, 0x7b, 0x24, 0x91
0xa3, 0xe0, 0xED, 0x43
<b>0x1a</b> , 0xc5, 0xc1, 0x3f
0x71, 0xf5, 0x75, 0xea
0x8f, 0x33, 0x24, 0x65
0xba, 0xba, 0x2c, 0xb0
0x15, 0x05, <b>0xa7</b> , 0x4b
0x42, 0x80, 0x9f, 0x62
0xed, 0x2a, 0xa0, 0x22
0x59, 0x2b, 0x2b, 0xbf
0x22, 0x2c, 0xDA, 0x0C

## 4.6 Sample Similarity Calculation

To test an implementation, the following sample **similarity data** computation is used for a **file**. The **similarity data** shown is as computed over the above set of **signatures**. Each value is displayed in hexadecimal.

t0	t1	t2	t3	t4	t5	t6	t7	T8	t9	t10	t11	t12	t13	t14	t15
2a	38	3a	37	09	0b	3b	01	3e	26	27	29	2a	01	14	39

## 4.7 Other Considerations

The size of **RDC chunks** can be shown mathematically to be on average two times the **horizon** size.

The minimum size of **RDC chunks** is usually the same as the **horizon** size. One exception to this rule is when there are less than **horizon**-size bytes of data left from the current **chunk** boundary to the end of the data. The other exception to this rule is when the maximum block size is exceeded.

The maximum **RDC chunk** size is  $2^{16}-1$  (65,535) bytes. One of the many possible examples of when this limit may be encountered is when large portions of the data (or all of the data) are the same (that is, all zeros or all ones). **RDC** automatically inserts a **cut point** to ensure that no block is larger than 65,535 bytes. If, for example, the first **local maximum** is found at position 65,540 in a **file**, there will be a **cut point** at positions 65,535 and 65,640; the second block being only 5-bytes long.

It is possible, of course, to apply **RDC** recursion to any number of levels. The depth of recursion that an application should use depends on the size of the **signature file** being transferred versus how many **chunks** of the **signature file** need to be transferred for each **recursion level**. The application must determine when bandwidth would be better utilized by just sending a bigger **signature file** to avoid another round of **signature** data transfer.

## 5 Security

### 5.1 Security Considerations for Implementers

**RDC** relies on a relatively weak **hash function** (that is, **MD4**) for its **chunks**. **MD4** was chosen because it requires few cycles per byte, has a relatively low startup cost (as several hashes are computed per *file*, one per **chunk**), and yet it is still a reasonably **collision-resistant hash function**. This is to be taken in the context in which the main functionality of **RDC** is to speed up sufficiently many (but not necessarily all) *file* transfers. **RDC** itself does not advertise that the transfer is accurate, but integrity **SHOULD** be checked by strong **hash functions**. Strong **hash functions** can be computed when traversing the source *file* and sent over at the end or beginning of a transfer.

Thus, it is possible (even to be expected—rarely) that two distinct **chunks** of data may have the same length and the same **MD4** hash value. In this case, it is possible that the use of **RDC** will result in the construction of a **target file** that is, in fact, distinct from the **source file**.

An application using **RDC** **SHOULD** have an alternate means outside of **RDC** to determine if the **target file** has the same content as the original **source file**.<7>

One way to achieve this goal is to compute a hash (using some application-selected hash algorithm) on the entire contents of the **source file** and the **target file**. If the hashes do not match, the application could invoke some sort of recovery operation (such as transferring the **source file** without the use of **RDC**). If it is possible that the input data to **RDC** is generated by a source that is not trustworthy, this secondary hash should be cryptographically secure, so that an attacker cannot intentionally generate a **file** update that could result in a **signature** collision and consequent errant transfer.

### 5.2 Index of Security Parameters

None.

## 6 Appendix A: Windows Behavior

The information in this specification is applicable to the following versions of Windows:

- Windows Server 2003
- Windows Vista
- Windows Server 2008

Exceptions, if any, are noted below. Unless otherwise specified, any statement of optional behavior in this specification prescribed using the terms SHOULD or SHOULD NOT implies Windows behavior in accordance with the SHOULD or SHOULD NOT prescription. Unless otherwise specified, the term MAY implies that Windows does not follow the prescription.

[<1> Section 3.1:](#) The **RDC** library uses only the **RDC FilterMax algorithm** to divide **files** into **chunks**. Providing the parameters to FilterMax is the responsibility of the user of **RDC**, and is not addressed in this document.

[<2> Section 3.1.5.1:](#) For an example of how Windows performs **hash window** and **horizon** negotiation, see [\[MS-FRS2\]](#) section 2.2.2.14.

[<3> Section 3.1.5.3.1:](#) The **RDC** library in Windows supports a maximum recursion depth of eight.

[<4> Section 3.1.5.3.1:](#) For more information on the determination of recursion depth, see [\[MS-FRS2\]](#) section 3.2.1.5.

[<5> Section 3.1.5.4:](#)

- For examples of the use of **similarity data**, see [\[MS-FRS2\]](#) sections [1.7](#), [2.2.1.2.1](#), and [2.2.1.4.4](#).
- If the **similarity data** appears in a protocol, the Windows-based **client** and **server** require that the **similarity data** MUST be computed by using the methods specified in section [3.1.5.4.1](#).

[<6> Section 3.1.5.4.2:](#) FRS2 (for more information, see [\[MS-FRS2\]](#)) may use several **seed files**, some of which it selects by finding the **files** that have the largest number of matching **similarity traits**. It also uses other techniques for finding **seed files**.

[<7> Section 5.1:](#) Windows Distributed File System (DFS) replication (for more information, see [\[MS-FRS2\]](#)), the only Microsoft component using **RDC** at the time of this writing, computes an SHA-1 hash (for more information, see [\[FIPS180-2\]](#)) over the contents of the **file**. And if it does not match, it transfers the **file** without using **RDC**.

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