Microsoft PPP CHAP Extensions, Version 2

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2. Abstract

The Point-to-Point Protocol (PPP) [1] provides a standard method for transporting multi-protocol datagrams over point-to-point links. PPP defines an extensible Link Control Protocol and a family of Network Control Protocols (NCPs) for establishing and configuring different network-layer protocols.

This document describes version two of Microsoft’s PPP CHAP dialect (MS-CHAP-V2). MS-CHAP-V2 is similar to, but incompatible with, MS-CHAP version one (MS-CHAP-V1, described in [9]). In particular, certain protocol fields have been deleted or reused but with different semantics. In addition, MS-CHAP-V2 features mutual authentication.

The algorithms used in the generation of various MS-CHAP-V2 protocol
fields are described in an appendix.

3. Introduction

Where possible, MS-CHAP-V2 is consistent with both MS-CHAP-V1 and standard CHAP. Briefly, the differences between MS-CHAP-V2 and MS-CHAP-V1 are:

* MS-CHAP-V2 is enabled by negotiating CHAP Algorithm 0x81 in LCP option 3, Authentication Protocol.

* MS-CHAP-V2 provides mutual authentication between peers by piggybacking a peer challenge on the Response packet and an authenticator response on the Success packet.

* The calculation of the "Windows NT compatible challenge response" sub-field in the Response packet has been changed to include the peer challenge and the user name.

* In MS-CHAP-V1, the "LAN Manager compatible challenge response" sub-field was always sent in the Response packet. This field has been replaced in MS-CHAP-V2 by the Peer-Challenge field.

* The format of the Message field in the Failure packet has been changed.

* The Change Password (version 1) and Change Password (version 2) packets are no longer supported. They have been replaced with a single Change-Password packet.

4. Specification of Requirements

In this document, the key words "MAY", "MUST", "MUST NOT", "optional", "recommended", "SHOULD", and "SHOULD NOT" are to be interpreted as described in [2].

5. LCP Configuration

The LCP configuration for MS-CHAP-V2 is identical to that for standard CHAP, except that the Algorithm field has value 0x81, rather than the MD5 value 0x05. PPP implementations which do not support MS-CHAP-V2, but correctly implement LCP Config-Rej, should have no problem dealing with this non-standard option.
6. Challenge Packet

The MS-CHAP-V2 Challenge packet is identical in format to the standard CHAP Challenge packet.

MS-CHAP-V2 authenticators send an 16-octet challenge Value field. Peers need not duplicate Microsoft’s algorithm for selecting the 16-octet value, but the standard guidelines on randomness [1,2,7] SHOULD be observed.

Microsoft authenticators do not currently provide information in the Name field. This may change in the future.

7. Response Packet

The MS-CHAP-V2 Response packet is identical in format to the standard CHAP Response packet. However, the Value field is sub-formatted differently as follows:

- 16 octets: Peer-Challenge
- 8 octets: Reserved, must be zero
- 24 octets: NT-Response
- 1 octet: Flags

The Peer-Challenge field is a 16-octet random number. As the name implies, it is generated by the peer and is used in the calculation of the NT-Response field, below. Peers need not duplicate Microsoft’s algorithm for selecting the 16-octet value, but the standard guidelines on randomness [1,2,7] SHOULD be observed.

The NT-Response field is an encoded function of the password, the user name, the contents of the Peer-Challenge field and the received challenge as output by the routine GenerateNTResponse() (see section A.1, below). The Windows NT password is a string of 0 to (theoretically) 256 case-sensitive Unicode [8] characters. Current versions of Windows NT limit passwords to 14 characters, mainly for compatibility reasons; this may change in the future. When computing the NT-Response field contents, only the user name is used, without any associated Windows NT domain name. This is true regardless of whether a Windows NT domain name is present in the Name field (see below).

The Flag field is reserved for future use and MUST be zero.

The Name field is a string of 0 to (theoretically) 256 case-sensitive ASCII characters which identifies the peer’s user account name. The Windows NT domain name may prefix the user’s account name (e.g. "BIGCO\johndoe" where "BIGCO" is a Windows NT domain containing the user
account "johndoe"). If a domain is not provided, the backslash should also be omitted, (e.g. "johndoe").

8. Success Packet

The Success packet is identical in format to the standard CHAP Success packet. However, the Message field contains a 42-octet authenticator response string of the form

"S=<auth_string>"

where <auth_string> is a 20 octet number encoded in ASCII as 40 hexadecimal digits. The hexadecimal digits A-F (if present) MUST be uppercase. This number is derived from the challenge from the Challenge packet, the Peer-Challenge and NT-Response fields from the Response packet, and the peer password as output by the routine GenerateAuthenticatorResponse() (see section A.6, below). The authenticating peer MUST verify the authenticator response when a Success packet is received. The method for verifying the authenticator is described in section A.7, below. If the authenticator response is either missing or incorrect, the peer MUST end the session.

9. Failure Packet

The Failure packet is identical in format to the standard CHAP Failure packet. There is, however, formatted text stored in the Message field which, contrary to the standard CHAP rules, does affect the operation of the protocol. The Message field format is:

"E=eeeeeeeeee R=r C=cccccccccccccccccccccccccccccccc V=vvvvvvvvvv"

where

The "eeeeeeeeee" is the ASCII representation of a decimal error code (need not be 10 digits) corresponding to one of those listed below, though implementations should deal with codes not on this list gracefully.

646 ERROR_RESTRICTED_LOGON_HOURS
647 ERROR_ACCT_DISABLED
648 ERROR_PASSWD_EXPIRED
649 ERROR_NO_DIALIN_PERMISSION
691 ERROR_AUTHENTICATION_FAILURE
709 ERROR_CHANGING_PASSWORD

The "r" is an ASCII flag set to ’1’ if a retry is allowed, and ’0’
if not. When the authenticator sets this flag to ‘1’ it disables short timeouts, expecting the peer to prompt the user for new credentials and resubmit the response.

The "cccccccccccccccccccccccccccc" is the ASCII representation of a hexadecimal challenge value. This field MUST be exactly 32 octets long and MUST be present.

The "vvvvvvvvvv" is the ASCII representation of a decimal version code (need not be 10 digits) indicating the password changing protocol version supported on the server. For MS-CHAP-V2, this value SHOULD always be 3.

Implementations should accept but ignore additional text they do not recognize.

10. Change-Password Packet

The Change-Password packet does not appear in either standard CHAP or MS-CHAP-V1. It allows the peer to change the password on the account specified in the preceding Response packet. The Change-Password packet should be sent only if the authenticator reports ERROR_PASSWD_EXPIRED (E=648) in the Message field of the Failure packet.

This packet type is supported by recent versions of Windows NT 4.0, Windows 95 and Windows 98. It is not supported by Windows NT 3.5, Windows NT 3.51, or early versions of Windows NT 4.0, Windows 95 and Windows 98.

The format of this packet is as follows:

1 octet : Code
1 octet : Identifier
2 octets : Length
516 octets : Encrypted-Password
16 octets : Encrypted-Hash
24 octets : Peer-Challenge
24 octets : NT-Response
2-octet : Flags

Code
7

Identifier
The Identifier field is one octet and aids in matching requests and replies. The value is the Identifier of the received Failure packet to which this packet responds plus 1.
Length
586

Encrypted-Password
This field contains the PWBLOCK form of the new Windows NT password encrypted with the old Windows NT password hash, as output by the NewPasswordEncryptedWithOldNtPasswordHash() routine (see section A.8, below).

Encrypted-Hash
This field contains the old Windows NT password hash encrypted with the new Windows NT password hash, as output by the OldNtPasswordHashEncryptedWithNewNtPasswordHash() routine (see section A.11, below).

Peer-Challenge
A 16-octet random quantity, as described in the Response packet description.

NT-Response
The NT-Response field (as described in the Response packet description), but calculated on the new password and the challenge received in the Failure packet.

Flags
This field is two octets in length. It is a bit field of option flags where 0 is the least significant bit of the 16-bit quantity. The format of this field is illustrated in the following diagram:

```
1
5 4 3 2 1 0 9 8 7 6 5 4 3 2 1 0
+-------------------------------------+
|                                     |
+-------------------------------------+
Bits 0-15
Reserved, always clear (0).
```

11. Security Considerations
As an implementation detail, the authenticator SHOULD limit the number of password retries allowed to make brute-force password guessing attacks more difficult.
12. References


[6] RC4 is a proprietary encryption algorithm available under license from RSA Data Security Inc. For licensing information, contact: RSA Data Security, Inc. 100 Marine Parkway Redwood City, CA 94065-1031


13. Acknowledgements

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16. Expiration Date

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Appendix A - Pseudocode

The routines mentioned in the text are described in pseudocode below.

A.1 GenerateNTResponse()

    GenerateNTResponse(
    IN 16-octet AuthenticatorChallenge,
    IN 16-octet PeerChallenge,
IN 0-to-256-char UserName,
IN 0-to-256-unicode-char Password,
OUT 24-octet Response )
{
  8-octet Challenge
  16-octet PasswordHash

  ChallengeHash( PeerChallenge, AuthenticatorChallenge, UserName, giving Challenge)
  NtPasswordHash( Password, giving PasswordHash )
  ChallengeResponse( Challenge, PasswordHash, giving Response )
}

A.2 ChallengeHash()

ChallengeHash(
IN 16-octet PeerChallenge,
IN 16-octet AuthenticatorChallenge,
IN 0-to-256-char UserName,
OUT 8-octet Challenge
)
{
  /*
   * SHAInit(), SHAUpdate() and SHAFinal() functions are an
   * implementation of Secure Hash Algorithm (SHA-1) [11]. These are
   * available in public domain or can be licensed from
   * RSA Data Security, Inc.
   */

  SHAInit(Context)
  SHAUpdate(Context, PeerChallenge, 16)
  SHAUpdate(Context, AuthenticatorChallenge, 16)

  /*
   * Only the user name (as presented by the peer and
   * excluding any prepended domain name)
   * is used as input to SHAUpdate().
   */

  SHAUpdate(Context, UserName, strlen(Username))
  SHAFinal(Context, Digest)
  memcpy(Challenge, Digest, 8)
}

A.3 NtPasswordHash()
NtPasswordHash(
IN 0-to-256-unicode-char Password,
OUT 16-octet PasswordHash )
{
/*
 * Use the MD4 algorithm [5] to irreversibly hash Password
 * into PasswordHash. Only the password is hashed without
 * including any terminating 0.
 */
}

A.4 ChallengeResponse()

ChallengeResponse(
IN 8-octet Challenge,
IN 16-octet PasswordHash,
OUT 24-octet Response )
{
    Set ZPasswordHash to PasswordHash zero-padded to 21 octets

    DesEncrypt( Challenge,
                1st 7-octets of ZPasswordHash,
                giving 1st 8-octets of Response )

    DesEncrypt( Challenge,
                2nd 7-octets of ZPasswordHash,
                giving 2nd 8-octets of Response )

    DesEncrypt( Challenge,
                3rd 7-octets of ZPasswordHash,
                giving 3rd 8-octets of Response )
}

A.5 DesEncrypt()

DesEncrypt(
IN 8-octet Clear,
IN 7-octet Key,
OUT 8-octet Cypher )
{
    /*
    * Use the DES encryption algorithm [4] in ECB mode [10]
    * to encrypt Clear into Cypher such that Cypher can
    * only be decrypted back to Clear by providing Key.
    * Note that the DES algorithm takes as input a 64-bit
    * stream where the 8th, 16th, 24th, etc. bits are
    */
parity bits ignored by the encrypting algorithm.
* Unless you write your own DES to accept 56-bit input
* without parity, you will need to insert the parity bits
* yourself.
*
}

A.6 GenerateAuthenticatorResponse()

GenerateAuthenticatorResponse(
  IN 0-to-256-unicode-char Password,
  IN 24-octet              NT-Response,
  IN 16-octet              PeerChallenge,
  IN 16-octet              AuthenticatorChallenge,
  IN 0-to-256-char         UserName,
  OUT 42-octet              AuthenticatorResponse )
{
  16-octet              PasswordHash
  16-octet              PasswordHashHash
  8-octet               Challenge

  /*
   * "Magic" constants used in response generation
   */
  Magic1[39] =
    {0x4D, 0x61, 0x67, 0x69, 0x63, 0x20, 0x73, 0x65, 0x72, 0x76,
     0x65, 0x72, 0x20, 0x74, 0x6F, 0x20, 0x63, 0x6C, 0x69, 0x6E,
     0x74, 0x20, 0x63, 0x6F, 0x73, 0x74, 0x61, 0x6E, 0x74};

  Magic2[41] =
    {0x50, 0x61, 0x64, 0x20, 0x74, 0x6F, 0x20, 0x6D, 0x61, 0x6B,
     0x65, 0x20, 0x69, 0x74, 0x20, 0x64, 0x6F, 0x20, 0x6D, 0x6F,
     0x72, 0x65, 0x20, 0x74, 0x68, 0x61, 0x6E, 0x20, 0x6F, 0x6E,
     0x65, 0x20, 0x69, 0x74, 0x65, 0x72, 0x61, 0x74, 0x69, 0x6E,
     0x74};

  /*
   * Hash the password with MD4
   */
  NtPasswordHash( Password, giving PasswordHash )

  /*
   * Now hash the hash
   */
HashNtPasswordHash( PasswordHash, giving PasswordHashHash)

SHAInit(Context)
SHAUpdate(Context, PasswordHashHash, 16)
SHAUpdate(Context, NtResponse, 24)
SHAUpdate(Context, Magic1, 39)
SHAFinal(Context, Digest)

ChallengeHash( PeerChallenge, AuthenticatorChallenge, UserName, giving Challenge)

SHAInit(Context)
SHAUpdate(Context, Digest, 20)
SHAUpdate(Context, Challenge, 8)
SHAUpdate(Context, Magic2, 41)
SHAFinal(Context, Digest)

/*
 * Encode the value of 'Digest' as "S=" followed by
 * 40 ASCII hexadecimal digits and return it in
 * AuthenticatorResponse.
 * For example,
 * "S=0123456789ABCDEF0123456789ABCDEF01234567"
 */

A.7 CheckAuthenticatorResponse()

CheckAuthenticatorResponse(
    IN 0-to-256-unicode-char Password,
    IN 24-octet NtResponse,
    IN 16-octet PeerChallenge,
    IN 16-octet AuthenticatorChallenge,
    IN 0-to-256-char UserName,
    IN 42-octet ReceivedResponse,
    OUT Boolean ResponseOK )
{

20-octet MyResponse

set ResponseOK = FALSE
GenerateAuthenticatorResponse( Password, NtResponse, PeerChallenge,
                              AuthenticatorChallenge, UserName,
                              giving MyResponse)

if (MyResponse = ReceivedResponse) then set ResponseOK = TRUE
return ResponseOK
}

A.8 NewPasswordEncryptedWithOldNtPasswordHash()

datatype-PWBLOCK
{  
  256-unicode-char Password
  4-octets PasswordLength
}

NewPasswordEncryptedWithOldNtPasswordHash(  
IN 0-to-256-unicode-char NewPassword,  
IN 0-to-256-unicode-char OldPassword,  
OUT datatype-PWBLOCK      EncryptedPwBlock )  
{  
  NtPasswordHash( OldPassword, giving PasswordHash )

  EncryptPwBlockWithPasswordHash( NewPassword,  
                                    PasswordHash,  
                                    giving EncryptedPwBlock )
}

A.9 EncryptPwBlockWithPasswordHash()

EncryptPwBlockWithPasswordHash(  
IN 0-to-256-unicode-char Password,  
IN 16-octet              PasswordHash,  
OUT datatype-PWBLOCK      PwBlock )  
{  
  Fill ClearPwBlock with random octet values
  PwSize = lstrlenW( Password ) * sizeof( unicode-char )
  PwOffset = sizeof( ClearPwBlock.Password ) - PwSize
  Move PwSize octets to (ClearPwBlock.Password + PwOffset ) from Password
  ClearPwBlock.PasswordLength = PwSize
  Rc4Encrypt( ClearPwBlock,  
              sizeof( ClearPwBlock ),  
              PasswordHash,  
              sizeof( PasswordHash ),  
              giving PwBlock )
}

A.10 Rc4Encrypt()
Rc4Encrypt(
IN x-octet Clear,
IN integer ClearLength,
IN y-octet Key,
IN integer KeyLength,
OUT x-octet Cypher )
{
   /*
   * Use the RC4 encryption algorithm [6] to encrypt Clear of
   * length ClearLength octets into a Cypher of the same length
   * such that the Cypher can only be decrypted back to Clear
   * by providing a Key of length KeyLength octets.
   */
}

A.11 OldNtPasswordHashEncryptedWithNewNtPasswordHash()

OldNtPasswordHashEncryptedWithNewNtPasswordHash(
IN 0-to-256-unicode-char NewPassword,
IN 0-to-256-unicode-char OldPassword,
OUT 16-octet EncryptedPasswordHash )
{
   NtPasswordHash( OldPassword, giving OldPasswordHash )
   NtPasswordHash( NewPassword, giving NewPasswordHash )
   NtPasswordHashEncryptedWithBlock( OldPasswordHash,
         NewPasswordHash,
         giving EncryptedPasswordHash )
}

A.12 NtPasswordHashEncryptedWithBlock()

NtPasswordHashEncryptedWithBlock(
IN 16-octet PasswordHash,
IN 16-octet Block,
OUT 16-octet Cypher )
{
   DesEncrypt( 1st 8-octets PasswordHash,
         1st 7-octets Block,
         giving 1st 8-octets Cypher )
   DesEncrypt( 2nd 8-octets PasswordHash,
         2nd 7-octets Block,
         giving 2nd 8-octets Cypher )
}

Appendix B - Examples
B.1 Negotiation Examples

Here are some examples of typical negotiations. The peer is on the left and the authenticator is on the right.

The packet sequence ID is incremented on each authentication retry Response and on the change password response. All cases where the packet sequence ID is updated are noted below.

Response retry is never allowed after Change Password. Change Password may occur after Response retry.

B.1.1 Successful authentication

<- Challenge
Response ->
  <- Success

B.1.2 Failed authentication with no retry allowed

<- Challenge
Response ->
  <- Failure (E=691 R=0)

B.1.3 Successful authentication after retry

<- Challenge
Response ->
  <- Failure (E=691 R=1), disable short timeout
Response (++ID) to challenge in failure message ->
  <- Success

B.1.4 Failed hack attack with 3 attempts allowed

<- Challenge
Response ->
  <- Failure (E=691 R=1), disable short timeout
Response (++ID) to challenge in Failure message ->
  <- Failure (E=691 R=1), disable short timeout
Response (++ID) to challenge in Failure message ->
  <- Failure (E=691 R=0)

B.1.5 Successful authentication with password change
<-- Challenge
Response ->
<-- Failure (E=648 R=0 V=3), disable short timeout
ChangePassword (++ID) to challenge in Failure message ->
<-- Success

B.1.6 Successful authentication with retry and password change

<-- Challenge
Response ->
<-- Failure (E=691 R=1), disable short timeout
Response (++ID) to first challenge+23 ->
<-- Failure (E=648 R=0 V=2), disable short timeout
ChangePassword (++ID) to first challenge+23 ->
<-- Success

B.2 Hash Example

Intermediate values for user name "User" and password "clientPass". All numeric values are hexadecimal.

  0-to-256-char UserName:
  55 73 65 72

  0-to-256-unicode-char Password:
  63 00 6C 00 69 00 65 00 6E 00 74 00 50 00 61 00 73 00 73 00

  16-octet AuthenticatorChallenge:
  5B 5D 7C 7D 7B 3F 2F 3E 3C 2C 60 21 32 26 26 28

  16-octet PeerChallenge:
  21 40 23 24 25 5E 26 2A 28 29 5F 2B 3A 33 7C 7E

  8-octet Challenge:
  D0 2E 43 86 BC E9 12 26

  16-octet PasswordHash:
  44 EB BA 8D 53 12 B8 D6 11 47 44 11 F5 69 89 AE

  24 octet NT-Response:
  82 30 9E CD 8D 70 8B 5E A0 8F AA 39 81 CD 83 54 42 33 11 4A 3D 85 D6 DF

  16-octet PasswordHashHash:
  41 C0 0C 58 4B D2 D9 1C 40 17 A2 A1 2F A5 9F 3F

  42-octet AuthenticatorResponse:
B.3 Example of DES Key Generation

DES uses 56-bit keys, expanded to 64 bits by the insertion of parity bits. After the parity of the key has been fixed, every eighth bit is a parity bit and the number of bits that are set (1) in each octet is odd; i.e., odd parity. Note that many DES engines do not check parity, however, simply stripping the parity bits. The following example illustrates the values resulting from the use of the password "MyPw" to generate a pair of DES keys (e.g., for use in the NtPasswordHashEncrypted-WithBlock() described in Appendix A.12).

0-to-256-unicode-char Password:
4D 79 50 77

16-octet PasswordHash:
FC 15 6A F7 ED CD 6C 0E DD E3 33 7D 42 7F 4E AC

First "raw" DES key (initial 7 octets of password hash):
FC 15 6A F7 ED CD 6C

First parity-corrected DES key (eight octets):
FD 0B 5B 5E 7F 6E 34 D9

Second "raw" DES key (second 7 octets of password hash)
0E DD E3 33 7D 42 7F

Second parity-corrected DES key (eight octets):
0E 6E 79 67 37 EA 08 FE