

Network Working Group  
Request for Comments: 2523  
Category: Experimental

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March 1999

## Photuris: Extended Schemes and Attributes

### Status of this Memo

This document defines an Experimental Protocol for the Internet community. It does not specify an Internet standard of any kind. Discussion and suggestions for improvement are requested. Distribution of this memo is unlimited.

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### Abstract

Photuris is a session-key management protocol. Extensible Exchange-Schemes are provided to enable future implementation changes without affecting the basic protocol.

Additional authentication attributes are included for use with the IP Authentication Header (AH) or the IP Encapsulating Security Protocol (ESP).

Additional confidentiality attributes are included for use with ESP.

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## 1. Additional Exchange-Schemes

The packet format and basic facilities are already defined for Photuris [RFC-2522].

These optional Exchange-Schemes are specified separately, and no single implementation is expected to support all of them.

This document defines the following values:

- (3) Implementation Optional. Any modulus (p) with a recommended generator (g) of 3. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

An Exchange-Scheme Size of zero is invalid.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"Simple Masking"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

- (4) Implementation Optional. Any modulus (p) with a recommended generator (g) of 2. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Scheme #2.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"DES-CBC over Mask"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

- (5) Implementation Optional. Any modulus (p) with a recommended generator (g) of 5. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

An Exchange-Scheme Size of zero is invalid.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"Simple Masking"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

- (6) Implementation Optional. Any modulus (p) with a recommended generator (g) of 3. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Scheme #3.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"DES-CBC over Mask"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

- (7) Implementation Optional. Any modulus (p) with a variable generator (g). When the Exchange-Scheme Size is non-zero, the pair [g,p] is contained in the Exchange-Scheme Value field in the list of Offered-Schemes. Each is encoded in a separate Variable Precision Integer (VPI). The generator VPI is followed by (concatenated to) the modulus VPI, and the result is nested inside the Exchange-Scheme Value field.

An Exchange-Scheme Size of zero is invalid.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"Simple Masking"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

When more than one modulus is specified for a given kind of Scheme, the Size of the modulus MUST be unique, independent of the Size of the generator.

- (8) Implementation Optional. Any modulus (p) with a recommended generator (g) of 2. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in

the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Schemes #2 and #4.

Key-Generation-Function	"SHA1 Hash"
Privacy-Method	"DES-EDE3-CBC over Mask"
Validity-Method	"SHA1-IPMAC Check"

This combination of features requires a modulus with at least 112-bits of cryptographic strength.

- (10) Implementation Optional. Any modulus (p) with a recommended generator (g) of 5. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Scheme #5.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"DES-CBC over Mask"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

- (12) Implementation Optional. Any modulus (p) with a recommended generator (g) of 3. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Schemes #3 and #6.

Key-Generation-Function	"SHA1 Hash"
Privacy-Method	"DES-EDE3-CBC over Mask"
Validity-Method	"SHA1-IPMAC Check"

This combination of features requires a modulus with at least 112-bits of cryptographic strength.

- (14) Implementation Optional. Any modulus (p) with a variable generator (g). When the Exchange-Scheme Size is non-zero, the pair [g,p] is contained in the Exchange-Scheme Value field in

the list of Offered-Schemes. Each is encoded in a separate Variable Precision Integer (VPI). The generator VPI is followed by (concatenated to) the modulus VPI, and the result is nested inside the Exchange-Scheme Value field.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Scheme #7.

Key-Generation-Function	"MD5 Hash"
Privacy-Method	"DES-CBC over Mask"
Validity-Method	"MD5-IPMAC Check"

This combination of features requires a modulus with at least 64-bits of cryptographic strength.

When more than one modulus is specified for a given kind of Scheme, the Size of the modulus MUST be unique, independent of the Size of the generator.

- (20) Implementation Optional. Any modulus (p) with a recommended generator (g) of 5. When the Exchange-Scheme Size is non-zero, the modulus is contained in the Exchange-Scheme Value field in the list of Offered-Schemes.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Schemes #5 and #10.

Key-Generation-Function	"SHA1 Hash"
Privacy-Method	"DES-EDE3-CBC over Mask"
Validity-Method	"SHA1-IPMAC Check"

This combination of features requires a modulus with at least 112-bits of cryptographic strength.

- (28) Implementation Optional. Any modulus (p) with a variable generator (g). When the Exchange-Scheme Size is non-zero, the pair [g,p] is contained in the Exchange-Scheme Value field in the list of Offered-Schemes. Each is encoded in a separate Variable Precision Integer (VPI). The generator VPI is followed by (concatenated to) the modulus VPI, and the result is nested inside the Exchange-Scheme Value field.

When the Exchange-Scheme Size field is zero, includes by reference all of the moduli specified in the list of Offered-Schemes for Schemes #7 and #14.

Key-Generation-Function	"SHA1 Hash"
Privacy-Method	"DES-EDE3-CBC over Mask"
Validity-Method	"SHA1-IPMAC Check"

This combination of features requires a modulus with at least 112-bits of cryptographic strength.

When more than one modulus is specified for a given kind of Scheme, the Size of the modulus MUST be unique, independent of the Size of the generator.

## 2. Additional Key-Generation-Function

### 2.1. SHA1 Hash

SHA1 [FIPS-180-1] is used as a pseudo-random-function for generating the key(s). The key(s) begin with the most significant bits of the hash. SHA1 is iterated as needed to generate the requisite length of key material.

When an individual key does not use all 160-bits of the last hash, any remaining unused (least significant) bits of the last hash are discarded. When combined with other uses of key generation for the same purpose, the next key will begin with a new hash iteration.

## 3. Additional Privacy-Methods

### 3.1. DES-CBC over Mask

As described in [RFC-2522] "Privacy-Key Computation", sufficient privacy-key material is generated to match the message length, beginning with the next field after the SPI, and including the Padding. The message is masked by XOR with the privacy-key.

Then, the Key-Generation-Function is iterated to generate a DES key. The most significant 64-bits (8 bytes) of the generated hash are used for the privacy-key, and the remainder are discarded. Although extremely rare, the 64 weak, semi-weak, and possibly weak keys [Schneier95, pages 280-282] are discarded. The Key-Generation-Function is iterated until a valid key is obtained.

The least significant bit of each key byte is ignored (or set to parity when the implementation requires).

The 64-bit CBC IV is zero. Message encryption begins with the next field after the SPI, and continues to the end of the data indicated

by the UDP Length.

### 3.2. DES-EDE3-CBC over Mask

This is "Triple DES" outer-CBC EDE encryption (and DED decryption) with three 56-bit keys [KR96].

As described in [RFC-2522] "Privacy-Key Computation", sufficient privacy-key material is generated to match the message length, beginning with the next field after the SPI, and including the Padding. The message is masked by XOR with the privacy-key.

Then, the Key-Generation-Function is iterated (at least) three times to generate the three DES keys. The most significant 64-bits (8 bytes) of each generated hash are used for each successive privacy-key, and the remainder are discarded. Each key is examined sequentially, in the order used for encryption. A key that is identical to a previous key MUST be discarded. Although extremely rare, the 64 weak, semi-weak, and possibly weak keys [Schneier95, pages 280-282] MUST be discarded. The Key-Generation-Function is iterated until a valid key is obtained before generating the next key.

In all three keys, the least significant bit of each key byte is ignored (or set to parity when the implementation requires).

The 64-bit CBC IV is zero. Message encryption begins with the next field after the SPI, and continues to the end of the data indicated by the UDP Length.

## 4. Additional Validity-Method

### 4.1. SHA1-IPMAC Check

As described in [RFC-2522] "Validity Verification", the Verification field value is the SHA1 [FIPS-180-1] hash over the concatenation of

```
SHA1( key, keyfill, data, datafill, key, mdfill )
```

where the key is the computed verification-key.

The keyfill and datafill use the same pad-with-length technique defined for mdfill. This padding and length is implicit, and does not appear in the datagram.

The resulting Verification field is a 160-bit Variable Precision Integer (22 bytes including Size). When used in calculations, the



Verification data includes both the Size and Value fields.

## 5. Additional Attributes

The attribute format and basic facilities are already defined for Photuris [RFC-2522].

These optional attributes are specified separately, and no single implementation is expected to support all of them.

This document defines the following values:

Use	Type	
AEI	6	SHA1-IPMAC
AEI	7	RIPEMD-160-IPMAC
E	8	DES-CBC
E	9	Invert (Decryption/Encryption)
E	10	XOR
A		AH Attribute-Choice
E		ESP Attribute-Choice
I		Identity-Choice
X		dependent on list location

### 5.1. SHA1-IPMAC

```

+---+---+---+---+---+---+---+---+---+---+---+---+
| Attribute | Length |
+---+---+---+---+---+---+---+---+---+---+---+---+

```

Attribute           6

Length             0

#### 5.1.1. Symmetric Identification

When selected as an Identity-Choice, the immediately following Identification field contains an unstructured Variable Precision Integer. Valid Identifications and symmetric secret-keys are preconfigured by the parties.

There is no required format or content for the Identification value. The value may be a number or string of any kind. See [RFC-2522] "Use of Identification and Secrets" for details.

The symmetric secret-key (as specified) is selected based on the contents of the Identification field. All implementations MUST support at least 62 bytes. The selected symmetric secret-key SHOULD provide at least 80-bits of cryptographic strength.

As described in [RFC-2522] "Identity Verification", the Verification field value is the SHA1 [FIPS-180-1] hash over the concatenation of:

```
SHA1( key, keyfill, data, datafill, key, mdfill )
```

where the key is the computed verification-key.

The keyfill and datafill use the same pad-with-length technique defined for mdfill. This padding and length is implicit, and does not appear in the datagram.

The resulting Verification field is a 160-bit Variable Precision Integer (22 bytes including Size). When used in calculations, the Verification data includes both the Size and Value fields.

For both [RFC-2522] "Identity Verification" and "Validity Verification", the verification-key is the SHA1 [FIPS-180-1] hash of the following concatenated values:

- + the symmetric secret-key,
- + the computed shared-secret.

For [RFC-2522] "Session-Key Computation", the symmetric secret-key is used directly as the generation-key.

The symmetric secret-key is used in calculations in the same fashion as [RFC-2522] "MD5-IPMAC Symmetric Identification".

### 5.1.2. Authentication

May be selected as an AH or ESP Attribute-Choice, pursuant to [RFC-1852] et sequitur. The selected Exchange-Scheme SHOULD provide at least 80-bits of cryptographic strength.

As described in [RFC-2522] "Session-Key Computation", the most significant 384-bits (48 bytes) of the Key-Generation-Function iterations are used for the key.

Profile:

When negotiated with Photuris, the transform differs slightly from [RFC-1852].

The form of the authenticated message is:

```
SHA1( key, keyfill, datagram, datafill, key, mdfill )
```

where the key is the SPI session-key.

The additional datafill protects against the attack described in [PO96]. The keyfill and datafill use the same pad-with-length technique defined for mdfill. This padding and length is implicit, and does not appear in the datagram.

### 5.2. RIPEMD-160-IPMAC

```
+---+---+---+---+---+---+---+---+---+---+
| Attribute | Length |
+---+---+---+---+---+---+---+---+---+---+
```

Attribute            7

Length              0

### 5.2.1. Symmetric Identification

When selected as an Identity-Choice, the immediately following Identification field contains an unstructured Variable Precision Integer. Valid Identifications and symmetric secret-keys are preconfigured by the parties.

There is no required format or content for the Identification value. The value may be a number or string of any kind. See [RFC-2522] "Use of Identification and Secrets" for details.

The symmetric secret-key (as specified) is selected based on the contents of the Identification field. All implementations MUST support at least 62 bytes. The selected symmetric secret-key SHOULD provide at least 80-bits of cryptographic strength.

As described in [RFC-2522] "Identity Verification", the Verification field value is the RIPEMD-160 [DBP96] hash over the concatenation of:

```
RIPEMD160( key, keyfill, data, datafill, key, mdfill )
```

where the key is the computed verification-key.

The keyfill and datafill use the same pad-with-length technique defined for mdfill. This padding and length is implicit, and does not appear in the datagram.

The resulting Verification field is a 160-bit Variable Precision Integer (22 bytes including Size). When used in calculations, the Verification data includes both the Size and Value fields.

For both [RFC-2522] "Identity Verification" and "Validity Verification", the verification-key is the RIPEMD-160 [DBP96] hash of the following concatenated values:

- + the symmetric secret-key,
- + the computed shared-secret.

For [RFC-2522] "Session-Key Computation", the symmetric secret-key is used directly as the generation-key.

The symmetric secret-key is used in calculations in the same fashion as [RFC-2522] "MD5-IPMAC Symmetric Identification".

### 5.2.2. Authentication

May be selected as an AH or ESP Attribute-Choice. The selected Exchange-Scheme SHOULD provide at least 80-bits of cryptographic strength.

As described in [RFC-2522] "Session-Key Computation", the most significant 384-bits (48 bytes) of the Key-Generation-Function iterations are used for the key.

Profile:

When negotiated with Photuris, the form of the authenticated message is:

```
RIPEMD160( key, keyfill, datagram, datafill, key, mdfill )
```

where the key is the SPI session-key.

The additional datafill protects against the attack described in [PO96]. The keyfill and datafill use the same pad-with-length technique defined for mdfill. This padding and length is implicit, and does not appear in the datagram.

### 5.3. DES-CBC

```
+-----+-----+-----+-----+-----+-----+-----+-----+
| Attribute | Length |
+-----+-----+-----+-----+-----+-----+-----+-----+
```

Attribute            8

Length               0

May be selected as an ESP Attribute-Choice, pursuant to [RFC-1829] et sequitur. The selected Exchange-Scheme SHOULD provide at least 56-bits of cryptographic strength.

As described in [RFC-2522] "Session-Key Computation", the most significant 64-bits (8 bytes) of the Key-Generation iteration are used for the key, and the remainder are discarded. Although extremely rare, the 64 weak, semi-weak, and possibly weak keys [Schneier95, pages 280-282] MUST be discarded. The Key-Generation-Function is iterated until a valid key is obtained.

The least significant bit of each key byte is ignored (or set to

parity when the implementation requires).

#### Profile:

When negotiated with Photuris, the transform differs slightly from [RFC-1829].

The 32-bit Security Parameters Index (SPI) field is followed by a 32-bit Sequence Number (SN).

The 64-bit CBC IV is generated from the 32-bit Security Parameters Index (SPI) field followed by (concatenated with) the 32-bit Sequence Number (SN) field. Then, the bit-wise complement of the 32-bit Sequence Number (SN) value is XOR'd with the first 32-bits (SPI):

$$(SPI \oplus \neg SN) \parallel SN$$

The Padding values begin with the value 1, and count up to the number of padding bytes. For example, if the plaintext length is 41, the padding values are 1, 2, 3, 4, 5, 6 and 7, plus any additional obscuring padding.

The PadLength and PayloadType are not appended. Instead, the PayloadType is indicated by the SPI, as specified by the ESP-Attributes attribute (#2).

After decryption, if the padding bytes are not the correct sequential values, then the payload is discarded, and a "Decryption Failed" error is indicated, as described in [RFC-2521].

#### 5.4. Invert (Decryption/Encryption)

```

+-----+-----+-----+-----+-----+-----+-----+-----+
| Attribute | Length |
+-----+-----+-----+-----+-----+-----+-----+-----+

```

Attribute            9

Length               0

May be selected as an ESP Attribute-Choice, immediately preceding an encryption choice. This indicates that the following attribute is inverted from encryption to decryption (or decryption to encryption) as the attributes are processed.

For example, the combination

```
"DES-CBC",
"Invert",
"DES-CBC",
"DES-CBC",
```

indicates "Triple DES" outer-CBC EDE encryption (and DED decryption) with three keys [KR96] pursuant to [RFC-1851] et sequitur. The selected Exchange-Scheme SHOULD provide at least 112-bits of cryptographic strength.

As described in [RFC-2522] "Session-Key Computation", the Key-Generation-Function is iterated (at least) three times to generate the three independent keys, in the order used for encryption. The most significant 64-bits (8 bytes) of each iteration are used for each successive key, and the remainder are discarded.

Each key is examined sequentially, in the order used for encryption. A key that is identical to any previous key MUST be discarded. Any weak keys indicated for the algorithm MUST be discarded. The Key-Generation-Function is iterated until a valid key is obtained before generating the next key.

Profile:

When negotiated with Photuris, the "DES-EDE3-CBC" transform differs slightly from [RFC-1851], in the same fashion as "DES-CBC" (described earlier).

## 5.5. XOR Whitening

```
+-----+-----+-----+-----+
| Attribute | Length |
+-----+-----+-----+-----+
```

Attribute            10

Length               0

May be selected as an ESP Attribute-Choice, pursuant to [XEX3] et sequitur. The combination

```
"XOR",
"DES-CBC",
"XOR",
```

indicates "DESX" encryption with three keys [KR96]. The selected Exchange-Scheme SHOULD provide at least 104-bits of cryptographic strength.

As described in [RFC-2522] "Session-Key Computation", the Key-Generation-Function is iterated (at least) three times to generate the three independent keys, in the order used for encryption. The most significant bytes of each iteration are used for each successive key, and the remainder are discarded.

Note that this attribute may appear multiple times in the same ESP attribute list, both before and after an encryption transform. For example,

```
"XOR",  
"DES-CBC",  
"XOR",  
"Invert",  
"DES-CBC",  
"XOR",  
"DES-CBC",  
"XOR",
```

would be one possible combination with Triple DES.



## A. Exchange-Scheme Selection

At first glance, there appear to be a large number of exchange-schemes. In practice, the selection is simple to automate.

Each scheme indicates a needed strength. This strength is based upon the functions used in protecting the Photuris Exchanges themselves.

Each keyed attribute also indicates a needed strength. This strength is based upon its cryptographic functions.

Because the usage of these functions is orthogonal, the same strength value can select an appropriate scheme that meets the needs of both features.

### A.1. Responder

The attributes to be offered to the particular Initiator are examined. For each level of strength specified, a scheme that meets or exceeds the requirements is offered.

For example, a Responder offering MD5-IPMAC and SHA1-IPMAC might offer scheme #2 with a 512-bit modulus and a 1024-bit modulus, and scheme #4 with a zero Size (indicating moduli of #2).

### A.2. Initiator

The strength indicated by the application for the Security Association, together with the party privacy policy of the system operator, is used to select from the offered schemes. The strength indicates the minimal level to be chosen, while the party privacy policy indicates whether to choose the minimal or maximal level of available protection.

For example, an application might indicate that it desires 80-bits of strength. In that case, only the 1024-bit modulus would be appropriate. The party privacy policy of the system operator would indicate whether to choose scheme #2 with "Simple Masking" or scheme #4 with "DES-CBC over Mask".

Alternatively, an application might indicate that it desires 64-bits of strength. The party privacy policy of the system operator would indicate whether to choose scheme #2 with the 512-bit modulus, or scheme #4 with the 1024-bit modulus.

## Security Considerations

Provision for multiple generators does not enhance the security of the Photuris protocol exchange itself. Rather, it provides an opportunity for novelty of moduli, by allowing more forms of moduli to be used. An abundance of moduli inhibits a determined attacker from pre-calculating moduli exchange values, and discourages dedication of resources for analysis of any particular modulus. That is, this protects the community of Photuris users.

In addition to preventing various attacks by protecting verification fields, the masking of the message plaintext before encryption is intended to obscure the relation of the number of parties and SPIs active between two IP nodes. The privacy mask dependency on the SPI and SPILT generates a different initial encrypted block for every SPI creation message.

This obscurement would be less effective when the SPI and SPILT are invariant or are not created for a particular exchange direction. The number of parties could be revealed by the number of exchanges with differences in the initial encrypted blocks.

## Acknowledgements

Phil Karn was principally responsible for the design of party privacy protection, and provided much of the design rationale text (now removed to a separate document).

William Simpson was responsible for the packet formats, and additional Exchange-Schemes, editing and formatting. All such mistakes are his responsibility.

Use of encryption for privacy protection is also found in the Station-To-Station authentication protocol [DOW92].

Bart Preneel and Paul C van Oorschot in [PO96] recommended padding between the data and trailing key when hashing for authentication.

Niels Provos developed the first implementation with multiple schemes and multiple moduli per scheme (circa July 1997).

Special thanks to the Center for Information Technology Integration (CITI) for providing computing resources.

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