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Privacy Enhancement for Internet Electronic Mail:
Part I -- Message Encipherment and Authentication Procedures

STATUS OF THIS MEMO

This RFC suggests a draft standard elective protocol for the Internet community, and requests discussion and suggestions for improvements. Distribution of this memo is unlimited.

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1. Executive Summary

This RFC defines message encipherment and authentication procedures, in order to provide privacy enhancement services for electronic mail transfer in the Internet. It is one member of a related set of four RFCs. The procedures defined in the current RFC are intended to be compatible with a wide range of key management approaches, including both symmetric (secret-key) and asymmetric (public-key) approaches for encryption of data encrypting keys. Use of symmetric cryptography for message text encryption and/or integrity check computation is anticipated. RFC-1114 specifies supporting key management mechanisms based on the use of public-key certificates. RFC-1115 specifies algorithm and related information relevant to the current RFC and to RFC-1114. A subsequent RFC will provide details of paper and electronic formats and procedures for the key management infrastructure being established in support of these services.

Privacy enhancement services (confidentiality, authentication, and

message integrity assurance) are offered through the use of end-to-end cryptography between originator and recipient User Agent processes, with no special processing requirements imposed on the Message Transfer System at endpoints or at intermediate relay sites. This approach allows privacy enhancement facilities to be incorporated on a site-by-site or user-by-user basis without impact on other Internet entities. Interoperability among heterogeneous components and mail transport facilities is supported.

2. Terminology

For descriptive purposes, this RFC uses some terms defined in the OSI X.400 Message Handling System Model per the 1984 CCITT Recommendations. This section replicates a portion of X.400's Section 2.2.1, "Description of the MHS Model: Overview" in order to make the terminology clear to readers who may not be familiar with the OSI MHS Model.

In the MHS model, a user is a person or a computer application. A user is referred to as either an originator (when sending a message) or a recipient (when receiving one). MH Service elements define the set of message types and the capabilities that enable an originator to transfer messages of those types to one or more recipients.

An originator prepares messages with the assistance of his or her User Agent (UA). A UA is an application process that interacts with the Message Transfer System (MTS) to submit messages. The MTS delivers to one or more recipient UAs the messages submitted to it. Functions performed solely by the UA and not standardized as part of the MH Service elements are called local UA functions.

The MTS is composed of a number of Message Transfer Agents (MTAs). Operating together, the MTAs relay messages and deliver them to the intended recipient UAs, which then make the messages available to the intended recipients.

The collection of UAs and MTAs is called the Message Handling System (MHS). The MHS and all of its users are collectively referred to as the Message Handling Environment.

3. Services, Constraints, and Implications

This RFC defines mechanisms to enhance privacy for electronic mail transferred in the Internet. The facilities discussed in this RFC provide privacy enhancement services on an end-to-end basis between sender and recipient UAs. No privacy enhancements are offered for message fields which are added or transformed by intermediate relay points.

Authentication and integrity facilities are always applied to the entirety of a message's text. No facility for confidentiality without authentication is provided. Encryption facilities may be applied selectively to portions of a message's contents; this allows less sensitive portions of messages (e.g., descriptive fields) to be processed by a recipient's delegate in the absence of the recipient's personal cryptographic keys. In the limiting case, where the entirety of message text is excluded from encryption, this feature can be used to yield the effective combination of authentication and integrity services without confidentiality.

In keeping with the Internet's heterogeneous constituencies and usage modes, the measures defined here are applicable to a broad range of Internet hosts and usage paradigms. In particular, it is worth noting the following attributes:

1. The mechanisms defined in this RFC are not restricted to a particular host or operating system, but rather allow interoperability among a broad range of systems. All privacy enhancements are implemented at the application layer, and are not dependent on any privacy features at lower protocol layers.
2. The defined mechanisms are compatible with non-enhanced Internet components. Privacy enhancements are implemented in an end-to-end fashion which does not impact mail processing by intermediate relay hosts which do not incorporate privacy enhancement facilities. It is necessary, however, for a message's sender to be cognizant of whether a message's intended recipient implements privacy enhancements, in order that encoding and possible encipherment will not be performed on a message whose destination is not equipped to perform corresponding inverse transformations.
3. The defined mechanisms are compatible with a range of mail transport facilities (MTAs). Within the Internet, electronic mail transport is effected by a variety of SMTP implementations. Certain sites, accessible via SMTP, forward mail into other mail processing environments (e.g., USENET, CSNET, BITNET). The privacy enhancements must be able to operate across the SMTP realm; it is desirable that they also be compatible with protection of electronic mail sent between the SMTP environment and other connected environments.
4. The defined mechanisms are compatible with a broad range of electronic mail user agents (UAs). A large variety of

electronic mail user agent programs, with a corresponding broad range of user interface paradigms, is used in the Internet. In order that electronic mail privacy enhancements be available to the broadest possible user community, selected mechanisms should be usable with the widest possible variety of existing UA programs. For purposes of pilot implementation, it is desirable that privacy enhancement processing be incorporable into a separate program, applicable to a range of UAs, rather than requiring internal modifications to each UA with which privacy-enhanced services are to be provided.

5. The defined mechanisms allow electronic mail privacy enhancement processing to be performed on personal computers (PCs) separate from the systems on which UA functions are implemented. Given the expanding use of PCs and the limited degree of trust which can be placed in UA implementations on many multi-user systems, this attribute can allow many users to process privacy-enhanced mail with a higher assurance level than a strictly UA-based approach would allow.
6. The defined mechanisms support privacy protection of electronic mail addressed to mailing lists (distribution lists, in ISO parlance).
7. The mechanisms defined within this RFC are compatible with a variety of supporting key management approaches, including (but not limited to) manual pre-distribution, centralized key distribution based on symmetric cryptography, and the use of public-key certificates. Different key management mechanisms may be used for different recipients of a multicast message. While support for a particular key management mechanism is not a minimum essential requirement for compatibility with this RFC, adoption of the public-key certificate approach defined in companion RFC-1114 is strongly recommended.

In order to achieve applicability to the broadest possible range of Internet hosts and mail systems, and to facilitate pilot implementation and testing without the need for prior modifications throughout the Internet, three basic restrictions are imposed on the set of measures to be considered in this RFC:

1. Measures will be restricted to implementation at endpoints and will be amenable to integration at the user agent (UA) level or above, rather than necessitating integration into the message transport system (e.g., SMTP servers).

2. The set of supported measures enhances rather than restricts user capabilities. Trusted implementations, incorporating integrity features protecting software from subversion by local users, cannot be assumed in general. In the absence of such features, it appears more feasible to provide facilities which enhance user services (e.g., by protecting and authenticating inter-user traffic) than to enforce restrictions (e.g., inter-user access control) on user actions.
3. The set of supported measures focuses on a set of functional capabilities selected to provide significant and tangible benefits to a broad user community. By concentrating on the most critical set of services, we aim to maximize the added privacy value that can be provided with a modest level of implementation effort.

As a result of these restrictions, the following facilities can be provided:

1. disclosure protection,
2. sender authenticity,
3. message integrity measures, and
4. (if asymmetric key management is used) non-repudiation of origin,

but the following privacy-relevant concerns are not addressed:

1. access control,
2. traffic flow confidentiality,
3. address list accuracy,
4. routing control,
5. issues relating to the casual serial reuse of PCs by multiple users,
6. assurance of message receipt and non-deniability of receipt,
7. automatic association of acknowledgments with the messages to which they refer, and
8. message duplicate detection, replay prevention, or other

stream-oriented services.

A message's sender will determine whether privacy enhancements are to be performed on a particular message. Therefore, a sender must be able to determine whether particular recipients are equipped to process privacy-enhanced mail. In a general architecture, these mechanisms will be based on server queries; thus, the query function could be integrated into a UA to avoid imposing burdens or inconvenience on electronic mail users.

4. Processing of Messages

4.1 Message Processing Overview

This subsection provides a high-level overview of the components and processing steps involved in electronic mail privacy enhancement processing. Subsequent subsections will define the procedures in more detail.

4.1.1 Types of Keys

A two-level keying hierarchy is used to support privacy-enhanced message transmission:

1. Data Encrypting Keys (DEKs) are used for encryption of message text and (with certain choices among a set of alternative algorithms) for computation of message integrity check (MIC) quantities. DEKs are generated individually for each transmitted message; no predistribution of DEKs is needed to support privacy-enhanced message transmission.
2. Interchange Keys (IKs) are used to encrypt DEKs for transmission within messages. Ordinarily, the same IK will be used for all messages sent from a given originator to a given recipient over a period of time. Each transmitted message includes a representation of the DEK(s) used for message encryption and/or MIC computation, encrypted under an individual IK per named recipient. The representation is associated with "X-Sender-ID:" and "X-Recipient-ID:" fields, which allow each individual recipient to identify the IK used to encrypt DEKs and/or MICs for that recipient's use. Given an appropriate IK, a recipient can decrypt the corresponding transmitted DEK representation, yielding the DEK required for message text decryption and/or MIC verification. The definition of an IK differs depending on whether symmetric or asymmetric cryptography is used for DEK encryption:

- 2a. When symmetric cryptography is used for DEK encryption, an IK is a single symmetric key shared between an originator and a recipient. In this case, the same IK is used to encrypt MICs as well as DEKs for transmission. Version/expiration information and IA identification associated with the originator and with the recipient must be concatenated in order to fully qualify a symmetric IK.
- 2b. When asymmetric cryptography is used, the IK component used for DEK encryption is the public component of the recipient. The IK component used for MIC encryption is the private component of the originator, and therefore only one encrypted MIC representation need be included per message, rather than one per recipient. Each of these IK components can be fully qualified in an "X-Recipient-ID:" or "X-Sender-ID:" field, respectively.

4.1.2 Processing Procedures

When privacy enhancement processing is to be performed on an outgoing message, a DEK is generated [1] for use in message encryption and (if a chosen MIC algorithm requires a key) a variant of the DEK is formed for use in MIC computation. DEK generation can be omitted for the case of a message in which all contents are excluded from encryption, unless a chosen MIC computation algorithm requires a DEK.

An "X-Sender-ID:" field is included in the header to provide one identification component for the IK(s) used for message processing. IK components are selected for each individually named recipient; a corresponding "X-Recipient-ID:" field, interpreted in the context of a prior "X-Sender-ID:" field, serves to identify each IK. Each "X-Recipient-ID:" field is followed by an "X-Key-Info:" field, which transfers a DEK encrypted under the IK appropriate for the specified recipient. When symmetric key management is used for a given recipient, the "X-Key-Info:" field also transfers the message's computed MIC, encrypted under the recipient's IK. When asymmetric key management is used, a prior "X-MIC-Info:" field carries the message's MIC encrypted under the private component of the sender.

A four-phase transformation procedure is employed in order to represent encrypted message text in a universally transmissible form and to enable messages encrypted on one type of host computer to be decrypted on a different type of host computer. A plaintext message is accepted in local form, using the host's native character set and

line representation. The local form is converted to a canonical message text representation, defined as equivalent to the inter-SMTP representation of message text. This canonical representation forms the input to the MIC computation and encryption processes.

For encryption purposes, the canonical representation is padded as required by the encryption algorithm. The padded canonical representation is encrypted (except for any regions which are explicitly excluded from encryption). The encrypted text (along with the canonical representation of regions which were excluded from encryption) is encoded into a printable form. The printable form is composed of a restricted character set which is chosen to be universally representable across sites, and which will not be disrupted by processing within and between MTS entities.

The output of the encoding procedure is combined with a set of header fields carrying cryptographic control information. The result is passed to the electronic mail system to be encapsulated as the text portion of a transmitted message.

When a privacy-enhanced message is received, the cryptographic control fields within its text portion provide the information required for the authorized recipient to perform MIC verification and decryption of the received message text. First, the printable encoding is converted to a bitstring. Encrypted portions of the transmitted message are decrypted. The MIC is verified. The canonical representation is converted to the recipient's local form, which need not be the same as the sender's local form.

4.2 Encryption Algorithms and Modes

For purposes of this RFC, the Block Cipher Algorithm DEA-1, defined in ANSI X3.92-1981 [2] shall be used for encryption of message text. The DEA-1 is equivalent to the Data Encryption Standard (DES), as defined in FIPS PUB 46 [3]. When used for encryption of text, the DEA-1 shall be used in the Cipher Block Chaining (CBC) mode, as defined in ISO IS 8372 [4]. The identifier string "DES-CBC", defined in RFC-1115, signifies this algorithm/mode combination. The CBC mode definition in IS 8372 is equivalent to that provided in FIPS PUB 81 [5] and in ANSI X3.106-1983 [16]. Use of other algorithms and/or modes for message text processing will require case-by-case study to determine applicability and constraints. Additional algorithms and modes approved for use in this context will be specified in successors to RFC-1115.

It is an originator's responsibility to generate a new pseudorandom initializing vector (IV) for each privacy-enhanced electronic mail message unless the entirety of the message is excluded from

encryption. Section 4.3.1 of [17] provides rationale for this requirement, even in a context where individual DEKs are generated for individual messages. The IV will be transmitted with the message.

Certain operations require that one key be encrypted under an interchange key (IK) for purposes of transmission. A header facility indicates the mode in which the IK is used for encryption. RFC-1115 specifies encryption algorithm/mode identifiers, including DES-ECB, DES-EDE, and RSA. All implementations using symmetric key management should support DES-ECB IK use, and all implementations using asymmetric key management should support RSA IK use.

RFC-1114, released concurrently with this RFC, specifies asymmetric, certificate-based key management procedures to support the message processing procedures defined in this document. The message processing procedures can also be used with symmetric key management, given prior distribution of suitable symmetric IKs through out-of-band means. Support for the asymmetric approach defined in RFC-1114 is strongly recommended.

4.3 Privacy Enhancement Message Transformations

4.3.1 Constraints

An electronic mail encryption mechanism must be compatible with the transparency constraints of its underlying electronic mail facilities. These constraints are generally established based on expected user requirements and on the characteristics of anticipated endpoint and transport facilities. An encryption mechanism must also be compatible with the local conventions of the computer systems which it interconnects. In our approach, a canonicalization step is performed to abstract out local conventions and a subsequent encoding step is performed to conform to the characteristics of the underlying mail transport medium (SMTP). The encoding conforms to SMTP constraints, established to support interpersonal messaging. SMTP's rules are also used independently in the canonicalization process. RFC-821's [7] Section 4.5 details SMTP's transparency constraints.

To prepare a message for SMTP transmission, the following requirements must be met:

1. All characters must be members of the 7-bit ASCII character set.
2. Text lines, delimited by the character pair <CR><LF>, must be no more than 1000 characters long.

3. Since the string <CR><LF>.<CR><LF> indicates the end of a message, it must not occur in text prior to the end of a message.

Although SMTP specifies a standard representation for line delimiters (ASCII <CR><LF>), numerous systems use a different native representation to delimit lines. For example, the <CR><LF> sequences delimiting lines in mail inbound to UNIX systems are transformed to single <LF>s as mail is written into local mailbox files. Lines in mail incoming to record-oriented systems (such as VAX VMS) may be converted to appropriate records by the destination SMTP [8] server. As a result, if the encryption process generated <CR>s or <LF>s, those characters might not be accessible to a recipient UA program at a destination which uses different line delimiting conventions. It is also possible that conversion between tabs and spaces may be performed in the course of mapping between inter-SMTP and local format; this is a matter of local option. If such transformations changed the form of transmitted ciphertext, decryption would fail to regenerate the transmitted plaintext, and a transmitted MIC would fail to compare with that computed at the destination.

The conversion performed by an SMTP server at a system with EBCDIC as a native character set has even more severe impact, since the conversion from EBCDIC into ASCII is an information-losing transformation. In principle, the transformation function mapping between inter-SMTP canonical ASCII message representation and local format could be moved from the SMTP server up to the UA, given a means to direct that the SMTP server should no longer perform that transformation. This approach has a major disadvantage: internal file (e.g., mailbox) formats would be incompatible with the native forms used on the systems where they reside. Further, it would require modification to SMTP servers, as mail would be passed to SMTP in a different representation than it is passed at present.

4.3.2 Approach

Our approach to supporting privacy-enhanced mail across an environment in which intermediate conversions may occur encodes mail in a fashion which is uniformly representable across the set of privacy-enhanced UAs regardless of their systems' native character sets. This encoded form is used to represent mail text from sender to recipient, but the encoding is not applied to enclosing mail transport headers or to encapsulated headers inserted to carry control information between privacy-enhanced UAs. The encoding's characteristics are such that the transformations anticipated between sender and recipient UAs will not prevent an encoded message from being decoded properly at its destination.

A sender may exclude one or more portions of a message from encryption processing, but authentication processing is always applied to the entirety of message text. Explicit action is required to exclude a portion of a message from encryption processing; by default, encryption is applied to the entirety of message text. The user-level delimiter which specifies such exclusion is a local matter, and hence may vary between sender and recipient, but all systems should provide a means for unambiguous identification of areas excluded from encryption processing.

An outbound privacy-enhanced message undergoes four transformation steps, described in the following four subsections.

4.3.2.1 Step 1: Local Form

The message text is created in the system's native character set, with lines delimited in accordance with local convention.

4.3.2.2 Step 2: Canonical Form

The entire message text, including both those portions subject to encipherment processing and those portions excluded from such processing, is converted to a universal canonical form, analogous to the inter-SMTP representation [9] as defined in RFC-821 and RFC-822 [10] (ASCII character set, <CR><LF> line delimiters). The processing required to perform this conversion is minimal on systems whose native character set is ASCII. (Note: Since the output of the canonical encoding process will never be submitted directly to SMTP, but only to subsequent steps of the privacy enhancement encoding process, the dot-stuffing transformation discussed in RFC-821, section 4.5.2, is not required.) Since a message is converted to a standard character set and representation before encryption, it can be decrypted and its MIC can be verified at any type of destination host computer. The decryption and MIC verification is performed before any conversions which may be necessary to transform the message into a destination-specific local form.

4.3.2.3 Step 3: Authentication and Encipherment

The canonical form is input to the selected MIC computation algorithm in order to compute an integrity check quantity for the message. No padding is added to the canonical form before submission to the MIC computation algorithm, although certain MIC algorithms will apply their own padding in the course of computing a MIC.

Padding is applied to the canonical form as needed to perform encryption in the DEA-1 CBC mode, as follows: The number of octets to be encrypted is determined by subtracting the number of octets

excluded from encryption from the total length of the canonically encoded text. Octets with the hexadecimal value FF (all ones) are appended to the canonical form as needed so that the text octets to be encrypted, along with the added padding octets, fill an integral number of 8-octet encryption quanta. No padding is applied if the number of octets to be encrypted is already an integral multiple of 8. The use of hexadecimal FF (a value outside the 7-bit ASCII set) as a padding value allows padding octets to be distinguished from valid data without inclusion of an explicit padding count indicator.

The regions of the message which have not been excluded from encryption are encrypted. To support selective encipherment processing, an implementation must retain internal indications of the positions of excluded areas excluded from encryption with relation to non-excluded areas, so that those areas can be properly delimited in the encoding procedure defined in step 4. If a region excluded from encryption intervenes between encrypted regions, cryptographic state (e.g., IVs and accumulation of octets into encryption quanta) is preserved and continued after the excluded region.

4.3.2.4 Step 4: Printable Encoding

Proceeding from left to right, the bit string resulting from step 3 is encoded into characters which are universally representable at all sites, though not necessarily with the same bit patterns (e.g., although the character "E" is represented in an ASCII-based system as hexadecimal 45 and as hexadecimal C5 in an EBCDIC-based system, the local significance of the two representations is equivalent). This encoding step is performed for all privacy-enhanced messages, even if an entire message is excluded from encryption.

A 64-character subset of International Alphabet IA5 is used, enabling 6 bits to be represented per printable character. (The proposed subset of characters is represented identically in IA5 and ASCII.) Two additional characters, "=" and "*", are used to signify special processing functions. The character "=" is used for padding within the printable encoding procedure. The character "*" is used to delimit the beginning and end of a region which has been excluded from encipherment processing. The encoding function's output is delimited into text lines (using local conventions), with each line except the last containing exactly 64 printable characters and the final line containing 64 or fewer printable characters. (This line length is easily printable and is guaranteed to satisfy SMTP's 1000-character transmitted line length limit.)

The encoding process represents 24-bit groups of input bits as output strings of 4 encoded characters. Proceeding from left to right across a 24-bit input group extracted from the output of step 3, each 6-bit

group is used as an index into an array of 64 printable characters. The character referenced by the index is placed in the output string. These characters, identified in Table 0, are selected so as to be universally representable, and the set excludes characters with particular significance to SMTP (e.g., ".", "<CR>", "<LF>").

Special processing is performed if fewer than 24 bits are available in an input group, either at the end of a message or (when the selective encryption facility is invoked) at the end of an encrypted region or an excluded region. A full encoding quantum is always completed at the end of a message and before the delimiter "*" is output to initiate or terminate the representation of a block excluded from encryption. When fewer than 24 input bits are available in an input group, zero bits are added (on the right) to form an integral number of 6-bit groups. Output character positions which are not required to represent actual input data are set to the character "=". Since all canonically encoded output is an integral number of octets, only the following cases can arise: (1) the final quantum of encoding input is an integral multiple of 24 bits; here, the final unit of encoded output will be an integral multiple of 4 characters with no "=" padding, (2) the final quantum of encoding input is exactly 8 bits; here, the final unit of encoded output will be two characters followed by two "=" padding characters, or (3) the final quantum of encoding input is exactly 16 bits; here, the final unit of encoded output will be three characters followed by one "=" padding character.

4.3.2.5 Summary of Transformations

In summary, the outbound message is subjected to the following composition of transformations:

$$\text{Transmit_Form} = \text{Encode}(\text{Encipher}(\text{Canonicalize}(\text{Local_Form})))$$

The inverse transformations are performed, in reverse order, to process inbound privacy-enhanced mail:

$$\text{Local_Form} = \text{DeCanonicalize}(\text{Decipher}(\text{Decode}(\text{Transmit_Form})))$$

Value	Encoding	Value	Encoding	Value	Encoding	Value	Encoding
0	A	17	R	34	i	51	z
1	B	18	S	35	j	52	0
2	C	19	T	36	k	53	1
3	D	20	U	37	l	54	2
4	E	21	V	38	m	55	3
5	F	22	W	39	n	56	4
6	G	23	X	40	o	57	5
7	H	24	Y	41	p	58	6
8	I	25	Z	42	q	59	7
9	J	26	a	43	r	60	8
10	K	27	b	44	s	61	9
11	L	28	c	45	t	62	+
12	M	29	d	46	u	63	/
13	N	30	e	47	v		
14	O	31	f	48	w	(pad)	=
15	P	32	g	49	x		
16	Q	33	h	50	y	(1)	*

(1) The character "*" is used to enclose portions of an encoded message to which encryption processing has not been applied.

Printable Encoding Characters
Table 1

Note that the local form and the functions to transform messages to and from canonical form may vary between the sender and recipient systems without loss of information.

4.4 Encapsulation Mechanism

Encapsulation of privacy-enhanced messages within an enclosing layer

of headers interpreted by the electronic mail transport system offers a number of advantages in comparison to a flat approach in which certain fields within a single header are encrypted and/or carry cryptographic control information. Encapsulation provides generality and segregates fields with user-to-user significance from those transformed in transit. All fields inserted in the course of encryption/authentication processing are placed in the encapsulated header. This facilitates compatibility with mail handling programs which accept only text, not header fields, from input files or from other programs. Further, privacy enhancement processing can be applied recursively. As far as the MTS is concerned, information incorporated into cryptographic authentication or encryption processing will reside in a message's text portion, not its header portion.

The encapsulation mechanism to be used for privacy-enhanced mail is derived from that described in RFC-934 [11] which is, in turn, based on precedents in the processing of message digests in the Internet community. To prepare a user message for encrypted or authenticated transmission, it will be transformed into the representation shown in Figure 1.

As a general design principle, sensitive data is protected by incorporating the data within the encapsulated text rather than by applying measures selectively to fields in the enclosing header. Examples of potentially sensitive header information may include fields such as "Subject:", with contents which are significant on an end-to-end, inter-user basis. The (possibly empty) set of headers to which protection is to be applied is a user option. It is strongly recommended, however, that all implementations should replicate copies of "X-Sender-ID:" and "X-Recipient-ID:" fields within the encapsulated text.

If a user wishes disclosure protection for header fields, they must occur only in the encapsulated text and not in the enclosing or encapsulated header. If disclosure protection is desired for a message's subject indication, it is recommended that the enclosing header contain a "Subject:" field indicating that "Encrypted Mail Follows".

If an authenticated version of header information is desired, that data can be replicated within the encapsulated text portion in addition to its inclusion in the enclosing header. For example, a sender wishing to provide recipients with a protected indication of a message's position in a series of messages could include a copy of a timestamp or message counter field within the encapsulated text.

A specific point regarding the integration of privacy-enhanced mail

facilities with the message encapsulation mechanism is worthy of note. The subset of IA5 selected for transmission encoding intentionally excludes the character "-", so encapsulated text can be distinguished unambiguously from a message's closing encapsulation boundary (Post-EB) without recourse to character stuffing.

Enclosing Header Portion

(Contains header fields per RFC-822)

Blank Line

(Separates Enclosing Header from Encapsulated Message)

Encapsulated Message**Pre-Encapsulation Boundary (Pre-EB)**

-----PRIVACY-ENHANCED MESSAGE BOUNDARY-----

Encapsulated Header Portion

(Contains encryption control fields inserted in plaintext. Examples include "X-DEK-Info:", "X-Sender-ID:", and "X-Key-Info:").

Note that, although these control fields have line-oriented representations similar to RFC-822 header fields, the set of fields valid in this context is disjoint from those used in RFC-822 processing.)

Blank Line

(Separates Encapsulated Header from subsequent encoded Encapsulated Text Portion)

Encapsulated Text Portion

(Contains message data encoded as specified in Section 4.3; may incorporate protected copies of enclosing and encapsulated header fields such as "Subject:", etc.)

Post-Encapsulation Boundary (Post-EB)

-----PRIVACY-ENHANCED MESSAGE BOUNDARY-----

Message Encapsulation**Figure 1****4.5 Mail for Mailing Lists**

When mail is addressed to mailing lists, two different methods of processing can be applicable: the IK-per-list method and the IK-per-recipient method. The choice depends on the information available to

the sender and on the sender's preference.

If a message's sender addresses a message to a list name or alias, use of an IK associated with that name or alias as a entity (IK-per-list), rather than resolution of the name or alias to its constituent destinations, is implied. Such an IK must, therefore, be available to all list members. For the case of asymmetric key management, the list's private component must be available to all list members. This alternative will be the normal case for messages sent via remote exploder sites, as a sender to such lists may not be cognizant of the set of individual recipients. Unfortunately, it implies an undesirable level of exposure for the shared IK, and makes its revocation difficult. Moreover, use of the IK-per-list method allows any holder of the list's IK to masquerade as another sender to the list for authentication purposes.

If, in contrast, a message's sender is equipped to expand the destination mailing list into its individual constituents and elects to do so (IK-per-recipient), the message's DEK (and, in the symmetric key management case, MIC) will be encrypted under each per-recipient IK and all such encrypted representations will be incorporated into the transmitted message. Note that per-recipient encryption is required only for the relatively small DEK and MIC quantities carried in the "X-Key-Info:" field, not for the message text which is, in general, much larger. Although more IKs are involved in processing under the IK-per-recipient method, the pairwise IKs can be individually revoked and possession of one IK does not enable a successful masquerade of another user on the list.

4.6 Summary of Encapsulated Header Fields

This section summarizes the syntax and semantics of the encapsulated header fields to be added to messages in the course of privacy enhancement processing. The fields are presented in three groups. Normally, the groups will appear in encapsulated headers in the order in which they are shown, though not all fields in each group will appear in all messages. In certain indicated cases, it is recommended that the fields be replicated within the encapsulated text portion as well as being included within the encapsulated header. Figures 2 and 3 show the appearance of small example encapsulated messages. Figure 2 assumes the use of symmetric cryptography for key management. Figure 3 illustrates an example encapsulated message in which asymmetric key management is used.

Unless otherwise specified, all field arguments are processed in a case-sensitive fashion. In most cases, numeric quantities are represented in header fields as contiguous strings of hexadecimal digits, where each digit is represented by a character from the


```

X-Key-Info: RSA,
  lBLpvXR0UrUzYbkNpk0agV2IzUpk8tEjmF/zxB+bATMtPjCUWbz8Lr9wloXIkjHU
X-Recipient-ID: privacy-tf@venera.isi.edu:RSADSI:4
X-Key-Info: RSA,
  NcUk2jHEUSoH1nvNSIWL9MLLrHB0eJzyhP+/fSStdW8okeEnv47jxe7SJ/iN72oh

LLrHB0eJzyhP+/fSStdW8okeEnv47jxe7SJ/iN72ohNcUk2jHEUSoH1nvNSIWL9M
8tEjmF/zxB+bATMtPjCUWbz8Lr9wloXIkjHULBLpvXR0UrUzYbkNpk0agV2IzUpk
J6UiRRGcDSvzrsoK+oNvqu6z7Xs5Xfz5rDqUcMLK1Z6720dcBWGGsDLpTpSCnpot
dXd/H5LMDWnonNvPCwQUHt==
-----PRIVACY-ENHANCED MESSAGE BOUNDARY-----

```

Example Encapsulated Message (Asymmetric Case)
Figure 3

Although the encapsulated header fields resemble RFC-822 header fields, they are a disjoint set and will not in general be processed by the same parser which operates on enclosing header fields. The complexity of lexical analysis needed and appropriate for encapsulated header field processing is significantly less than that appropriate to RFC-822 header processing. For example, many characters with special significance to RFC-822 at the syntactic level have no such significance within encapsulated header fields.

When the length of an encapsulated header field is longer than the size conveniently printable on a line, whitespace may be used to fold the field in the manner of RFC-822, section 3.1.1. Any such inserted whitespace is not to be interpreted as a part of a subfield. As a particular example, due to the length of public-key certificates and of quantities encrypted using asymmetric algorithms, such quantities may often need to be folded across multiple printed lines. In order to facilitate such folding in a uniform manner, the bits representing such a quantity are to be divided into an ordered set (with leftmost bits first) of zero or more 384-bit groups (corresponding to 64-character printed representations), followed by a final group of bits which may be any length up to 384 bits.

4.6.1 Per-Message Encapsulated Header Fields

This group of encapsulated header fields contains fields which occur no more than once in a privacy-enhanced message, generally preceding all other encapsulated header fields.

4.6.1.1 X-Proc-Type Field

The "X-Proc-Type:" encapsulated header field, required for all privacy-enhanced messages, identifies the type of processing

performed on the transmitted message. Only one "X-Proc-Type:" field occurs in a message; the "X-Proc-Type:" field must be the first encapsulated header field in the message.

The "X-Proc-Type:" field has two subfields, separated by a comma. The first subfield is a decimal number which is used to distinguish among incompatible encapsulated header field interpretations which may arise as changes are made to this standard. Messages processed according to this RFC will carry the subfield value "3" to distinguish them from messages processed in accordance with prior RFCs 989 and 1040.

The second subfield may assume one of two string values: "ENCRYPTED" or "MIC-ONLY". Unless all of a message's encapsulated text is excluded from encryption, the "X-Proc-Type:" field's second subfield must specify "ENCRYPTED". Specification of "MIC-ONLY", when applied in conjunction with certain combinations of key management and MIC algorithm options, permits certain fields which are superfluous in the absence of encryption to be omitted from the encapsulated header. In particular, "X-Recipient-ID:" and "X-Key-Info:" fields can be omitted for recipients for whom asymmetric cryptography is used, assuming concurrent use of a keyless MIC computation algorithm. The "X-DEK-Info:" field can be omitted for all "MIC-ONLY" messages.

4.6.1.2 X-DEK-Info Field

The "X-DEK-Info:" encapsulated header field identifies the message text encryption algorithm and mode, and also carries the Initializing Vector used for message encryption. No more than one "X-DEK-Info:" field occurs in a message; the field is required except for messages specified as "MIC-ONLY" in the "X-Proc-Type:" field.

The "X-DEK-Info:" field carries two arguments, separated by a comma. For purposes of this RFC, the first argument must be the string "DES-CBC", signifying (as defined in RFC-1115) use of the DES algorithm in the CBC mode. The second argument represents a 64-bit Initializing Vector (IV) as a contiguous string of 16 hexadecimal digits. Subsequent revisions of RFC-1115 will specify any additional values which may appear as the first argument of this field.

4.6.2 Encapsulated Header Fields Normally Per-Message

This group of encapsulated header fields contains fields which ordinarily occur no more than once per message. Depending on the key management option(s) employed, some of these fields may be absent from some messages. The "X-Sender-ID" field may occur more than once in a message if different sender-oriented IK components (perhaps corresponding to different versions) must be used for different

recipients. In this case later occurrences override prior occurrences. If a mixture of symmetric and asymmetric key distribution is used within a single message, the recipients for each type of key distribution technology should be grouped together to simplify parsing.

4.6.2.1 X-Sender-ID Field

The "X-Sender-ID:" encapsulated header field, required for all privacy-enhanced messages, identifies a message's sender and provides the sender's IK identification component. It should be replicated within the encapsulated text. The IK identification component carried in an "X-Sender-ID:" field is used in conjunction with all subsequent "X-Recipient-ID:" fields until another "X-Sender-ID:" field occurs; the ordinary case will be that only a single "X-Sender-ID:" field will occur, prior to any "X-Recipient-ID:" fields.

The "X-Sender-ID:" field contains (in order) an Entity Identifier subfield, an (optional) Issuing Authority subfield, and an (optional) Version/Expiration subfield. The optional subfields are omitted if their use is rendered redundant by information carried in subsequent "X-Recipient-ID:" fields; this will ordinarily be the case where symmetric cryptography is used for key management. The subfields are delimited by the colon character (":"), optionally followed by whitespace.

Section 5.2, Interchange Keys, discusses the semantics of these subfields and specifies the alphabet from which they are chosen. Note that multiple "X-Sender-ID:" fields may occur within a single encapsulated header. All "X-Recipient-ID:" fields are interpreted in the context of the most recent preceding "X-Sender-ID:" field; it is illegal for an "X-Recipient-ID:" field to occur in a header before an "X-Sender-ID:" has been provided.

4.6.2.2 X-Certificate Field

The "X-Certificate:" encapsulated header field is used only when asymmetric key management is employed for one or more of a message's recipients. To facilitate processing by recipients (at least in advance of general directory server availability), inclusion of this field in all messages is strongly recommended. The field transfers a sender's certificate as a numeric quantity, represented with the encoding mechanism defined in Section 4.3.2.4 of this RFC. The semantics of a certificate are discussed in RFC-1114. The certificate carried in an "X-Certificate:" field is used in conjunction with "X-Sender-ID:" and "X-Recipient-ID:" fields for which asymmetric key management is employed.

4.6.2.3 X-MIC-Info Field

The "X-MIC-Info:" encapsulated header field, used only when asymmetric key management is employed for at least one recipient of a message, carries three arguments, separated by commas. The first argument identifies the algorithm under which the accompanying MIC is computed; RFC-1115 specifies the acceptable set of MIC algorithm identifiers. The second argument identifies the algorithm under which the accompanying MIC is encrypted; for purposes of this RFC, the string "RSA" as described in RFC-1115 must occur, identifying use of the RSA algorithm. The third argument is a MIC, asymmetrically encrypted using the originator's private component. As discussed earlier in this section, the asymmetrically encrypted MIC is represented using the technique described in Section 4.3.2.4 of this RFC.

The "X-MIC-Info:" field will occur immediately following the message's "X-Sender-ID:" field and any "X-Certificate:" or "X-Issuer-Certificate:" fields. Analogous to the "X-Sender-ID:" field, an "X-MIC-Info:" field applies to all subsequent recipients for whom asymmetric key management is used.

4.6.3 Encapsulated Header Fields with Variable Occurrences

This group of encapsulated header fields contains fields which will normally occur variable numbers of times within a message, with numbers of occurrences ranging from zero to non-zero values which are independent of the number of recipients.

4.6.3.1 X-Issuer-Certificate Field

The "X-Issuer-Certificate:" encapsulated header field is meaningful only when asymmetric key management is used for at least one of a message's recipients. A typical "X-Issuer-Certificate:" field would contain the certificate containing the public component used to sign the certificate carried in the message's "X-Certificate:" field, for recipients' use in chaining through that certificate's certification path. Other "X-Issuer-Certificate:" fields, typically representing higher points in a certification path, also may be included by a sender. The order in which "X-Issuer-Certificate:" fields are included need not correspond to the order of the certification path; the order of that path may in general differ from the viewpoint of different recipients. More information on certification paths can be found in RFC-1114.

The certificate is represented in the same manner as defined for the "X-Certificate:" field, and any "X-Issuer-Certificate:" fields will ordinarily follow the "X-Certificate:" field directly. Use of the

"X-Issuer-Certificate:" field is optional even when asymmetric key management is employed, although its incorporation is strongly recommended in the absence of alternate directory server facilities from which recipients can access issuers' certificates.

4.6.4 Per-Recipient Encapsulated Header Fields

This group of encapsulated header fields normally appears once for each of a message's named recipients. As a special case, these fields may be omitted in the case of a "MIC-ONLY" message to recipients for whom asymmetric key management is employed, given that the chosen MIC algorithm is keyless.

4.6.4.1 X-Recipient-ID Field

The "X-Recipient-ID:" encapsulated header field identifies a recipient and provides the recipient's IK identification component. One "X-Recipient-ID:" field is included for each of a message's named recipients. It should be replicated within the encapsulated text. The field contains (in order) an Entity Identifier subfield, an Issuing Authority subfield, and a Version/Expiration subfield. The subfields are delimited by the colon character (":"), optionally followed by whitespace.

Section 5.2, Interchange Keys, discusses the semantics of the subfields and specifies the alphabet from which they are chosen. All "X-Recipient-ID:" fields are interpreted in the context of the most recent preceding "X-Sender-ID:" field; it is illegal for an "X-Recipient-ID:" field to occur in a header before an "X-Sender-ID:" has been provided.

4.6.4.2 X-Key-Info Field

One "X-Key-Info:" field is included for each of a message's named recipients. Each "X-Key-Info:" field is interpreted in the context of the most recent preceding "X-Recipient-ID:" field; normally, an "X-Key-Info:" field will immediately follow its associated "X-Recipient-ID:" field. The field's argument(s) differ depending on whether symmetric or asymmetric key management is used for a particular recipient.

4.6.4.2.1 Symmetric Key Management

When symmetric key management is employed for a given recipient, the "X-Key-Info:" encapsulated header field transfers four items, separated by commas: an IK Use Indicator, a MIC Algorithm Indicator, a DEK and a MIC. The IK Use Indicator identifies the algorithm and mode in which the identified IK was used for DEK encryption for a

particular recipient. For recipients for whom symmetric key management is used, it may assume the reserved string values "DES-ECB" or "DES-EDE", as defined in RFC-1115.

The MIC Algorithm Indicator identifies the MIC computation algorithm used for a particular recipient; values for this subfield are defined in RFC-1115. The DEK and MIC are encrypted under the IK identified by a preceding "X-Recipient-ID:" field and prior "X-Sender-ID:" field; they are represented as two strings of contiguous hexadecimal digits, separated by a comma.

When DEA-1 is used for message text encryption, the DEK representation will be 16 hexadecimal digits (corresponding to a 64-bit key); this subfield can be extended to 32 hexadecimal digits (corresponding to a 128-bit key) if required to support other algorithms.

Symmetric encryption of MICs is always performed in the same encryption mode used to encrypt the message's DEK. Encrypted MICs, like encrypted DEKs, are represented as contiguous strings of hexadecimal digits. The size of a MIC is dependent on the choice of MIC algorithm as specified in the MIC Algorithm Indicator subfield.

4.6.4.2.2 Asymmetric Key Management

When asymmetric key management is employed for a given recipient, the "X-Key-Info:" field transfers two quantities, separated by commas. The first argument is an IK Use Indicator identifying the algorithm (and mode, if applicable) in which the DEK is encrypted; for purposes of this RFC, the IK Use Indicator subfield will always assume the reserved string value "RSA" (as defined in RFC-1115) for recipients for whom asymmetric key management is employed, signifying use of the RSA algorithm. The second argument is a DEK, encrypted (using asymmetric encryption) under the recipient's public component.

Throughout this RFC we have adopted the terms "private component" and "public component" to refer to the quantities which are, respectively, kept secret and made publically available in asymmetric cryptosystems. This convention is adopted to avoid possible confusion arising from use of the term "secret key" to refer to either the former quantity or to a key in a symmetric cryptosystem.

As discussed earlier in this section, the asymmetrically encrypted DEK is represented using the technique described in Section 4.3.2.4 of this RFC.

5. Key Management

Several cryptographic constructs are involved in supporting the privacy-enhanced message processing procedure. A set of fundamental elements is assumed. Data Encrypting Keys (DEKs) are used to encrypt message text and (for some MIC computation algorithms) in the message integrity check (MIC) computation process. Interchange Keys (IKs) are used to encrypt DEKs and MICs for transmission with messages. In a certificate-based asymmetric key management architecture, certificates are used as a means to provide entities' public components and other information in a fashion which is securely bound by a central authority. The remainder of this section provides more information about these constructs.

5.1 Data Encrypting Keys (DEKs)

Data Encrypting Keys (DEKs) are used for encryption of message text and (with some MIC computation algorithms) for computation of message integrity check quantities (MICs). It is strongly recommended that DEKs be generated and used on a one-time, per-message, basis. A transmitted message will incorporate a representation of the DEK encrypted under an appropriate interchange key (IK) for each of the named recipients.

DEK generation can be performed either centrally by key distribution centers (KDCs) or by endpoint systems. Dedicated KDC systems may be able to implement stronger algorithms for random DEK generation than can be supported in endpoint systems. On the other hand, decentralization allows endpoints to be relatively self-sufficient, reducing the level of trust which must be placed in components other than a message's originator and recipient. Moreover, decentralized DEK generation at endpoints reduces the frequency with which senders must make real-time queries of (potentially unique) servers in order to send mail, enhancing communications availability.

When symmetric cryptography is used, one advantage of centralized KDC-based generation is that DEKs can be returned to endpoints already encrypted under the IKs of message recipients rather than providing the IKs to the senders. This reduces IK exposure and simplifies endpoint key management requirements. This approach has less value if asymmetric cryptography is used for key management, since per-recipient public IK components are assumed to be generally available and per-sender private IK components need not necessarily be shared with a KDC.

5.2 Interchange Keys (IKs)

Interchange Key (IK) components are used to encrypt DEKs and MICs.

In general, IK granularity is at the pairwise per-user level except for mail sent to address lists comprising multiple users. In order for two principals to engage in a useful exchange of privacy-enhanced electronic mail using conventional cryptography, they must first possess common IK components (when symmetric key management is used) or complementary IK components (when asymmetric key management is used). When symmetric cryptography is used, the IK consists of a single component, used to encrypt both DEKs and MICs. When asymmetric cryptography is used, a recipient's public component is used as an IK to encrypt DEKs (a transformation invertible only by a recipient possessing the corresponding private component), and the originator's private component is used to encrypt MICs (a transformation invertible by all recipients, since the originator's certificate provides the necessary public component of the originator).

While this RFC does not prescribe the means by which interchange keys are provided to appropriate parties, it is useful to note that such means may be centralized (e.g., via key management servers) or decentralized (e.g., via pairwise agreement and direct distribution among users). In any case, any given IK component is associated with a responsible Issuing Authority (IA). When certificate-based asymmetric key management, as discussed in RFC-1114, is employed, the IA function is performed by a Certification Authority (CA).

When an IA generates and distributes an IK component, associated control information is provided to direct how it is to be used. In order to select the appropriate IK(s) to use in message encryption, a sender must retain a correspondence between IK components and the recipients with which they are associated. Expiration date information must also be retained, in order that cached entries may be invalidated and replaced as appropriate.

Since a message may be sent with multiple IK components identified, corresponding to multiple intended recipients, each recipient's UA must be able to determine that recipient's intended IK component. Moreover, if no corresponding IK component is available in the recipient's database when a message arrives, the recipient must be able to identify the required IK component and identify that IK component's associated IA. Note that different IKs may be used for different messages between a pair of communicants. Consider, for example, one message sent from A to B and another message sent (using the IK-per-list method) from A to a mailing list of which B is a member. The first message would use IK components associated individually with A and B, but the second would use an IK component shared among list members.

When a privacy-enhanced message is transmitted, an indication of the

IK components used for DEK and MIC encryption must be included. To this end, the "X-Sender-ID:" and "X-Recipient-ID:" encapsulated header fields provide the following data:

1. Identification of the relevant Issuing Authority (IA subfield)
2. Identification of an entity with which a particular IK component is associated (Entity Identifier or EI subfield)
3. Version/Expiration subfield

The colon character (":") is used to delimit the subfields within an "X-Sender-ID:" or "X-Recipient-ID:". The IA, EI, and version/expiration subfields are generated from a restricted character set, as prescribed by the following BNF (using notation as defined in RFC-822, sections 2 and 3.3):

```
IKsubfld      :=      1*ia-char
ia-char       :=      DIGIT / ALPHA / "'" / "+" / "(" / ")" /
                        "\"" / ":" / "/" / "=" / "?" / "-" / "@" /
                        "%" / "!" / "!" / " " / "<" / ">"
```

An example "X-Recipient-ID:" field is as follows:

X-Recipient-ID: linn@ccy.bbn.com:ptf-kmc:2

This example field indicates that IA "ptf-kmc" has issued an IK component for use on messages sent to "linn@ccy.bbn.com", and that the IA has provided the number 2 as a version indicator for that IK component.

5.2.1 Subfield Definitions

The following subsections define the subfields of "X-Sender-ID:" and "X-Recipient-ID:" fields.

5.2.1.1 Entity Identifier Subfield

An entity identifier is constructed as an IKsubfld. More restrictively, an entity identifier subfield assumes the following form:

<user>@<domain-qualified-host>

In order to support universal interoperability, it is necessary to assume a universal form for the naming information. For the case of installations which transform local host names before transmission into the broader Internet, it is strongly recommended that the host

name as presented to the Internet be employed.

5.2.1.2 Issuing Authority Subfield

An IA identifier subfield is constructed as an IKsubfld. IA identifiers must be assigned in a manner which assures uniqueness. This can be done on a centralized or hierarchic basis.

5.2.1.3 Version/Expiration Subfield

A version/expiration subfield is constructed as an IKsubfld. The version/expiration subfield format may vary among different IAs, but must satisfy certain functional constraints. An IA's version/expiration subfields must be sufficient to distinguish among the set of IK components issued by that IA for a given identified entity. Use of a monotonically increasing number is sufficient to distinguish among the IK components provided for an entity by an IA; use of a timestamp additionally allows an expiration time or date to be prescribed for an IK component.

5.2.2 IK Cryptoperiod Issues

An IK component's cryptoperiod is dictated in part by a tradeoff between key management overhead and revocation responsiveness. It would be undesirable to delete an IK component permanently before receipt of a message encrypted using that IK component, as this would render the message permanently undecipherable. Access to an expired IK component would be needed, for example, to process mail received by a user (or system) which had been inactive for an extended period of time. In order to enable very old IK components to be deleted, a message's recipient desiring encrypted local long term storage should transform the DEK used for message text encryption via re-encryption under a locally maintained IK, rather than relying on IA maintenance of old IK components for indefinite periods.

6. User Naming

6.1 Current Approach

Unique naming of electronic mail users, as is needed in order to select corresponding keys correctly, is an important topic and one which has received significant study. Our current architecture associates IK components with user names represented in a universal form ("user@domain-qualified-host"), relying on the following properties:

1. The universal form must be specifiable by an IA as it distributes IK components and known to a UA as it processes

received IK components and IK component identifiers. If a UA or IA uses addresses in a local form which is different from the universal form, it must be able to perform an unambiguous mapping from the universal form into the local representation.

2. The universal form, when processed by a sender UA, must have a recognizable correspondence with the form of a recipient address as specified by a user (perhaps following local transformation from an alias into a universal form).

It is difficult to ensure these properties throughout the Internet. For example, an MTS which transforms address representations between the local form used within an organization and the universal form as used for Internet mail transmission may cause property 2 to be violated.

6.2 Issues for Consideration

The use of flat (non-hierarchical) electronic mail user identifiers, which are unrelated to the hosts on which the users reside, may offer value. As directory servers become more widespread, it may become appropriate for would-be senders to search for desired recipients based on such attributes. Personal characteristics, like social security numbers, might be considered. Individually-selected identifiers could be registered with a central authority, but a means to resolve name conflicts would be necessary.

A point of particular note is the desire to accommodate multiple names for a single individual, in order to represent and allow delegation of various roles in which that individual may act. A naming mechanism that binds user roles to keys is needed. Bindings cannot be immutable since roles sometimes change (e.g., the comptroller of a corporation is fired).

It may be appropriate to examine the prospect of extending the DARPA/DoD domain system and its associated name servers to resolve user names to unique user IDs. An additional issue arises with regard to mailing list support: name servers do not currently perform (potentially recursive) expansion of lists into users. ISO and CSNet are working on user-level directory service mechanisms, which may also bear consideration.

7. Example User Interface and Implementation

In order to place the mechanisms and approaches discussed in this RFC into context, this section presents an overview of a prototype implementation. This implementation is a standalone program which is

invoked by a user, and lies above the existing UA sublayer. In the UNIX system, and possibly in other environments as well, such a program can be invoked as a "filter" within an electronic mail UA or a text editor, simplifying the sequence of operations which must be performed by the user. This form of integration offers the advantage that the program can be used in conjunction with a range of UA programs, rather than being compatible only with a particular UA.

When a user wishes to apply privacy enhancements to an outgoing message, the user prepares the message's text and invokes the standalone program (interacting with the program in order to provide address information and other data required to perform privacy enhancement processing), which in turn generates output suitable for transmission via the UA. When a user receives a privacy-enhanced message, the UA delivers the message in encrypted form, suitable for decryption and associated processing by the standalone program.

In this prototype implementation (based on symmetric key management), a cache of IK components is maintained in a local file, with entries managed manually based on information provided by originators and recipients. This cache is, effectively, a simple database. IK components are selected for transmitted messages based on the sender's identity and on recipient names, and corresponding "X-Sender-ID:" and "X-Recipient-ID:" fields are placed into the message's encapsulated header. When a message is received, these fields are used as a basis for a lookup in the database, yielding the appropriate IK component entries. DEKs and IVs are generated dynamically within the program.

Options and destination addresses are selected by command line arguments to the standalone program. The function of specifying destination addresses to the privacy enhancement program is logically distinct from the function of specifying the corresponding addresses to the UA for use by the MTS. This separation results from the fact that, in many cases, the local form of an address as specified to a UA differs from the Internet global form as used in "X-Sender-ID:" and "X-Recipient-ID:" fields.

8. Areas For Further Study

The procedures defined in this RFC are sufficient to support implementation of privacy-enhanced electronic mail transmission among cooperating parties in the Internet. Further effort will be needed, however, to enhance robustness, generality, and interoperability. In particular, further work is needed in the following areas:

1. User naming techniques, and their relationship to the domain system, name servers, directory services, and key management

functions.

2. Detailed standardization of Issuing Authority and directory service functions and interactions.
3. Privacy-enhanced interoperability with X.400 mail.

We anticipate generation of subsequent RFCs which will address these topics.

9. References

This section identifies background references which may be useful to those contemplating use of the mechanisms defined in this RFC.

ISO 7498/Part 2 - Security Architecture, prepared by ISO/TC97/SC 21/WG 1 Ad hoc group on Security, extends the OSI Basic Reference Model to cover security aspects which are general architectural elements of communications protocols, and provides an annex with tutorial and background information.

US Federal Information Processing Standards Publication (FIPS PUB) 46, Data Encryption Standard, 15 January 1977, defines the encipherment algorithm used for message text encryption and Message Authentication Code (MAC) computation.

FIPS PUB 81, DES Modes of Operation, 2 December 1980, defines specific modes in which the Data Encryption Standard algorithm may to be used to perform encryption.

FIPS PUB 113, Computer Data Authentication, May 1985, defines a specific procedure for use of the Data Encryption Standard algorithm to compute a MAC.

NOTES:

- [1] Key generation for MIC computation and message text encryption may either be performed by the sending host or by a centralized server. This RFC does not constrain this design alternative. Section 5.1 identifies possible advantages of a centralized server approach if symmetric key management is employed.
- [2] American National Standard Data Encryption Algorithm (ANSI X3.92-1981), American National Standards Institute, Approved 30 December 1980.
- [3] Federal Information Processing Standards Publication 46, Data Encryption Standard, 15 January 1977.

- [4] Information Processing Systems: Data Encipherment: Modes of Operation of a 64-bit Block Cipher.
- [5] Federal Information Processing Standards Publication 81, DES Modes of Operation, 2 December 1980.
- [6] ANSI X9.17-1985, American National Standard, Financial Institution Key Management (Wholesale), American Bankers Association, April 4, 1985, Section 7.2.
- [7] Postel, J., "Simple Mail Transfer Protocol" RFC-821, USC/Information Sciences Institute, August 1982.
- [8] This transformation should occur only at an SMTP endpoint, not at an intervening relay, but may take place at a gateway system linking the SMTP realm with other environments.
- [9] Use of the SMTP canonicalization procedure at this stage was selected since it is widely used and implemented in the Internet community, not because SMTP interoperability with this intermediate result is required; no privacy-enhanced message will be passed to SMTP for transmission directly from this step in the four-phase transformation procedure.
- [10] Crocker, D., "Standard for the Format of ARPA Internet Text Messages", RFC-822, August 1982.
- [11] Rose, M. and E. Stefferud, "Proposed Standard for Message Encapsulation", RFC-934, January 1985.
- [12] CCITT Recommendation X.411 (1988), "Message Handling Systems: Message Transfer System: Abstract Service Definition and Procedures".
- [13] CCITT Recommendation X.509 (1988), "The Directory - Authentication Framework".
- [14] Kille, S., "Mapping between X.400 and RFC-822", RFC-987, June 1986.
- [15] Federal Information Processing Standards Publication 113, Computer Data Authentication, May 1985.
- [16] American National Standard for Information Systems - Data Encryption Algorithm - Modes of Operation (ANSI X3.106-1983), American National Standards Institute - Approved 16 May 1983.
- [17] Voydock, V. and S. Kent, "Security Mechanisms in High-Level

Network Protocols", ACM Computing Surveys, Vol. 15, No. 2, Pages 135-171, June 1983.

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