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Transmission of IPv6 over MS/TP Networks
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Abstract

MS/TP (Master-Slave/Token-Passing) is a contention-free access method for the RS-485 physical layer that is used extensively in building automation networks. This document describes the frame format for transmission of IPv6 packets and the method of forming link-local and statelessly autoconfigured IPv6 addresses on MS/TP networks.

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1. Introduction

MS/TP (Master-Slave/Token-Passing) is a contention-free access method for the RS-485 [TIA-485-A] physical layer that is used extensively in building automation networks. This document describes the frame format for transmission of IPv6 [RFC2460] packets and the method of forming link-local and statelessly autoconfigured IPv6 addresses on MS/TP networks. The general approach is to adapt elements of the 6LoWPAN [RFC4944] specification to constrained wired networks.

An MS/TP device is typically based on a low-cost microcontroller with limited processing power and memory. Together with low data rates and a small address space, these constraints are similar to those faced in 6LoWPAN networks and suggest some elements of that solution might be applied. MS/TP differs significantly from 6LoWPAN in at least three respects: a) MS/TP devices typically have a continuous source of power, b) all MS/TP devices on a segment can communicate directly so there are no hidden node or mesh routing issues, and c) proposed changes to MS/TP will support payloads of up to 1501 octets, eliminating the need for link-layer fragmentation and reassembly.

The following sections provide a brief overview of MS/TP, then describe how to form IPv6 addresses and encapsulate IPv6 packets in MS/TP frames. This document also specifies a header compression mechanism, based on [RFC6282], that is recommended in order to make IPv6 practical on low speed MS/TP networks.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

1.2. Abbreviations Used

ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (http://www.ashrae.org)

BACnet: An ISO/ANSI/ASHRAE Standard Data Communication Protocol for Building Automation and Control Networks

CRC: Cyclic Redundancy Check

MAC: Medium Access Control

MSDU: MAC Service Data Unit (MAC client data)

UART: Universal Asynchronous Transmitter/Receiver

1.3. MS/TP Overview

This section provides a brief overview of MS/TP, which is specified in Clause 9 of ANSI/ASHRAE 135-2010 [BACnet] and included herein by reference. [BACnet] also covers physical layer deployment options.

MS/TP is designed to enable multidrop networks over shielded twisted pair wiring. It can support segments up to 1200 meters in length or data rates up to 115,200 baud (at this highest data rate the segment length is limited to 1000 meters). An MS/TP link requires only a UART, a 5ms resolution timer, and a [TIA-485-A] transceiver with a driver that can be disabled. These features combine to make MS/TP a cost-effective field bus for the most numerous and least expensive devices in a building automation network.

The differential signaling used by [TIA-485-A] requires a contention-free MAC. MS/TP uses a token to control access to a multidrop bus. A master node may initiate the transmission of a data frame when it holds the token. After sending at most a configured maximum number of data frames, a master node passes the token to the next master node (as determined by node address). Slave nodes transmit only when polled and are not considered part of this specification.

MS/TP frames have the following format*:

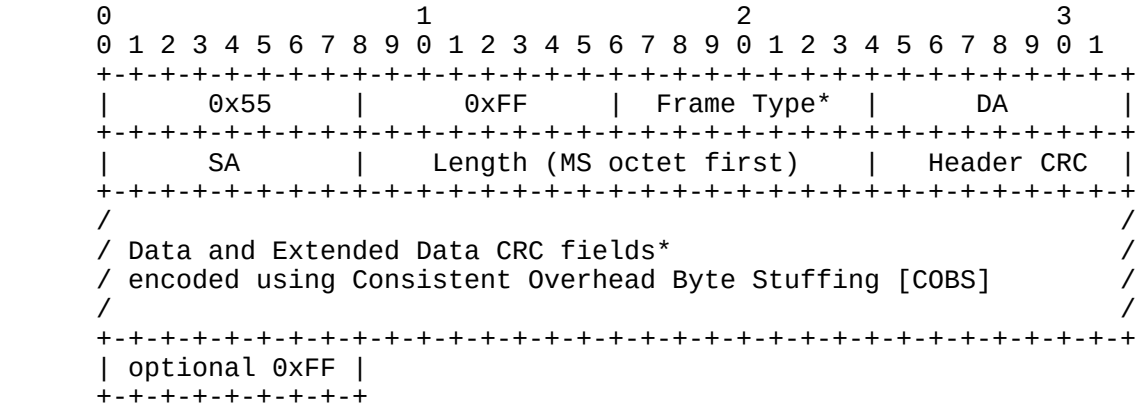


Figure 1: MS/TP Extended Frame Format

*Note: A BACnet proposal [Addendum_an], now in public review, assigns a new Frame Type for IPv6 Encapsulation, extends the maximum length of the Data field to 1501 octets, and specifies a 32-bit Extended Data CRC [CRC32K] for these frames. The Data and Extended Data CRC fields are [COBS] encoded and present only if Length is non-zero.

The MS/TP frame fields have the following descriptions**:

Preamble	two octet preamble: 0x55, 0xFF
Frame Type	one octet
Destination Address	one octet address
Source Address	one octet address
Length	two octets, most significant octet first
Header CRC	one octet
Data	0 - 1501 octets** (present only if Length is non-zero)
Extended Data CRC	four octets**, least significant octet first (present only if Length is non-zero)
(pad)	(optional) at most one octet of trailer: 0xFF

The Frame Type is used to distinguish between different types of MAC frames. Currently defined types (in decimal) are:

```
00  Token
01  Poll For Master
02  Reply To Poll For Master
    ...
10  IPv6 over MS/TP Encapsulation**
```

Frame Types 11 through 127 are reserved for assignment by ASHRAE. All master nodes MUST understand Token, Poll For Master, and Reply to Poll For Master frames. See Section 2 for additional details.

The Destination and Source Addresses are each one octet in length. See Section 3 for additional details.

A non-zero Length field specifies the length of the [COBS] encoded Data and Extended Data CRC fields in octets, minus two. (Note: This trick is required for co-existence with legacy MS/TP devices.) See Section 4 and Appendices for additional details.

The Header CRC field covers the Frame Type, Destination Address, Source Address, and Length fields. The Header CRC generation and check procedures are specified in [BACnet].

**The Data and Extended Data CRC fields are conditional on the Frame Type and the Length and will always be present in frames specified by this document. These fields are concatenated and then encoded before transmission using Consistent Overhead Byte Stuffing [COBS] to remove preamble sequences from the fields. The Extended Data CRC and COBS encoding procedures are specified in the BACnet [Addendum_an] change proposal and briefly summarized in Appendices A and B below.

1.4. Goals and Non-goals

The primary goal of this specification is to enable IPv6 directly to wired end devices in building automation and control networks, while leveraging existing standards to the greatest extent possible. A secondary goal is to co-exist with legacy MS/TP implementations. Only the minimum changes necessary to support IPv6 over MS/TP are proposed in BACnet [Addendum_an] (see note in Section 1.3).

Non-goals include making changes to the MS/TP frame header format, control frames, Master Node state machine, or addressing modes. Also, while the techniques described here may be applicable to other data links, no attempt is made to define a general design pattern.

2. MS/TP Mode for IPv6

The BACnet [Addendum_an] change proposal allocates a new MS/TP Frame Type from the ASHRAE reserved range to indicate IPv6 Encapsulation. The new Frame Type for IPv6 Encapsulation is 10 (0x0A).

All MS/TP master nodes (including those that support IPv6) must understand Token, Poll For Master, and Reply to Poll For Master control frames and support the Master Node state machine as specified in [BACnet]. MS/TP master nodes that support IPv6 must also support the Receive Frame state machine as specified in [BACnet] as extended by [Addendum_an].

3. Addressing Modes

MS/TP node (link-layer) addresses are one octet in length. The method of assigning node addresses is outside the scope of this document. However, each MS/TP node on the link MUST have a unique address or a misconfiguration condition exists.

[BACnet] specifies that addresses 0 through 127 are valid for master nodes. The method specified in Section 6 for creating the Interface Identifier (IID) ensures that an IID of all zeros can never result.

A Destination Address of 255 (0xFF) denotes a link-level broadcast (all nodes). A Source Address of 255 MUST NOT be used. MS/TP does not support multicast, therefore all IPv6 multicast packets MUST be sent as link-level broadcasts and filtered at the IPv6 layer.

This document assumes that each MS/TP link maps onto a unique IPv6 subnet prefix. Hosts learn IPv6 prefixes via router advertisements according to [RFC4861].

4. Maximum Transmission Unit (MTU)

The BACnet [Addendum_an] change proposal specifies that the MSDU be increased to 1501 octets and covered by a 32-bit CRC. This is sufficient to convey an MTU of at least 1280 octets as required by IPv6 without the need for link-layer fragmentation and reassembly.

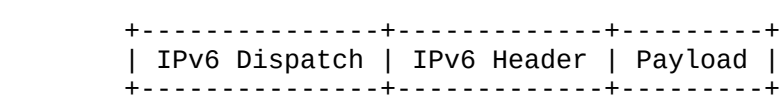
However, the relatively low data rates of MS/TP still make a compelling case for header compression. An adaptation layer to indicate compressed or uncompressed IPv6 headers is specified below in Section 5 and the compression scheme is specified in Section 10.

5. LoBAC Adaptation Layer

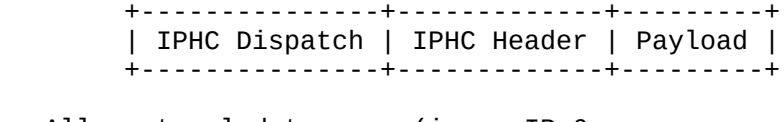
The encapsulation formats defined in this section (subsequently referred to as the "LoBAC" encapsulation) comprise the payload (MSDU) of an MS/TP frame. The LoBAC payload (i.e., an IPv6 packet) follows an encapsulation header stack. LoBAC is a subset of the LoWPAN encapsulation defined in [RFC4944], therefore the use of "LOWPAN" in literals below is intentional. The primary differences between LoBAC and LoWPAN are: a) exclusion of the Fragmentation, Mesh, and Broadcast headers, and b) use of LOWPAN_IPHC [RFC6282] in place of LOWPAN_HC1 header compression (which is deprecated by [RFC6282]).

All LoBAC encapsulated datagrams transmitted over MS/TP are prefixed by an encapsulation header stack. Each header in the stack consists of a header type followed by zero or more header fields. Whereas in an IPv6 header the stack would contain, in the following order, addressing, hop-by-hop options, routing, fragmentation, destination options, and finally payload [RFC2460]; in a LoBAC encapsulation the analogous sequence is (optional) header compression and payload. The header stacks that are valid in a LoBAC network are shown below.

A LoBAC encapsulated IPv6 datagram:



A LoBAC encapsulated LOWPAN_IPHC compressed IPv6 datagram:



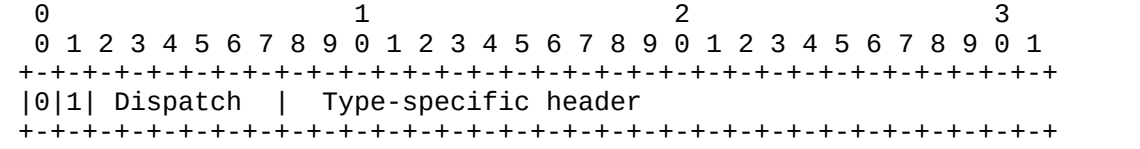
All protocol datagrams (i.e., IPv6 or compressed IPv6 headers) SHALL be preceded by one of the valid LoBAC encapsulation headers. This

permits uniform software treatment of datagrams without regard to their mode of transmission.

The definition of LoBAC headers consists of the dispatch value, the definition of the header fields that follow, and their ordering constraints relative to all other headers. Although the header stack structure provides a mechanism to address future demands on the LoBAC (LoWPAN) adaptation layer, it is not intended to provided general purpose extensibility. This format document specifies a small set of header types using the header stack for clarity, compactness, and orthogonality.

5.1. Dispatch Value and Header

The LoBAC Dispatch value begins with a "0" bit followed by a "1" bit. The Dispatch value and header are shown here:



Dispatch — 6-bit selector. Identifies the type of header immediately following the Dispatch value.

Type-specific header — A header determined by the Dispatch value.

Figure 2: Dispatch Value and Header

The Dispatch value may be treated as an unstructured namespace. Only a few symbols are required to represent current LoBAC functionality. Although some additional savings could be achieved by encoding additional functionality into the dispatch value, these measures would tend to constrain the ability to address future alternatives.

Pattern	Header Type	
00 xxxxxx	NALP	- Not a LoWPAN (LoBAC) frame
01 000000	ESC	- Additional Dispatch octet follows
01 000001	IPv6	- Uncompressed IPv6 Addresses
...	reserved	- Defined or reserved by [RFC4944]
01 1xxxxx	LOWPAN_IPHC	- LOWPAN_IPHC compressed IPv6 [RFC6282]
1x xxxxxx	reserved	- Defined or reserved by [RFC4944]

Figure 3: Dispatch Value Bit Patterns

NALP: Specifies that the following bits are not a part of the LoBAC encapsulation, and any LoBAC node that encounters a Dispatch value of 00xxxxxx shall discard the packet. Non-LoBAC protocols that wish to coexist with LoBAC nodes should include an octet matching this pattern immediately following the MS/TP header.

ESC: Specifies that the following header is a single 8-bit field for the Dispatch value. It allows support for Dispatch values larger than 127 (see [RFC6282] section 5).

IPv6: Specifies that the following header is an uncompressed IPv6 header [RFC2460].

LOWPAN_IPHC: A value of 011xxxxx specifies a LOWPAN_IPHC compression header (see Section 10.)

Reserved: A LoBAC node that encounters a Dispatch value in the range 01000010 through 01011111 or 1xxxxxxx SHALL discard the packet.

6. Stateless Address Autoconfiguration

This section defines how to obtain an IPv6 Interface Identifier. The general procedure is described in Appendix A of [RFC4291], "Creating Modified EUI-64 Format Interface Identifiers".

The Interface Identifier may be based on an [EUI-64] identifier assigned to the device (but this is not typical for MS/TP). In this case, the Interface Identifier is formed from the EUI-64 by inverting the "u" (universal/local) bit according to [RFC4291]. This will result in a globally unique Interface Identifier.

If the device does not have an EUI-64, then the Interface Identifier MUST be formed by concatenating its 8-bit MS/TP node address to the seven octets 0x00, 0x00, 0x00, 0xFF, 0xFE, 0x00, 0x00. For example, an MS/TP node address of hexadecimal value 0x4F results in the following Interface Identifier:

```
|0              1|1              3|3              4|4              6|
|0              5|6              1|2              7|8              3|
+----------------+----------------+----------------+----------------+
|0000000000000000|0000000011111111|1111111000000000|0000000001001111|
+----------------+----------------+----------------+----------------+
```

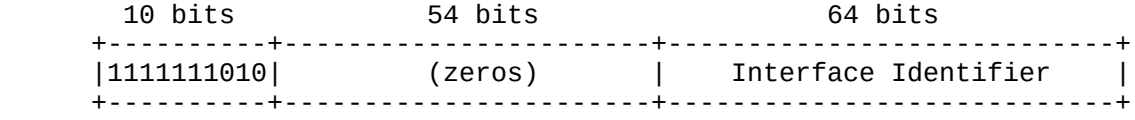
Note that this results in the universal/local bit set to "0" to indicate local scope.

An IPv6 address prefix used for stateless autoconfiguration [RFC4862]

of an MS/TP interface MUST have a length of 64 bits.

7. IPv6 Link Local Address

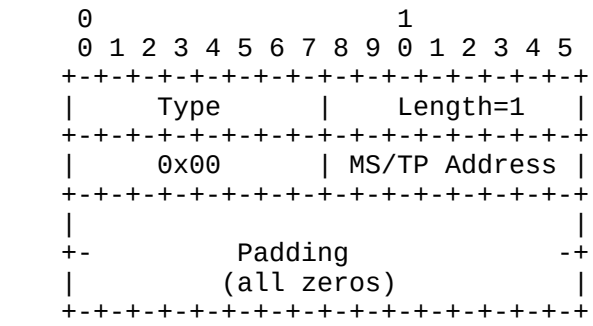
The IPv6 link-local address [RFC4291] for an MS/TP interface is formed by appending the Interface Identifier, as defined above, to the prefix FE80::/64.



8. Unicast Address Mapping

The address resolution procedure for mapping IPv6 non-multicast addresses into MS/TP link-layer addresses follows the general description in Section 7.2 of [RFC4861], unless otherwise specified.

The Source/Target Link-layer Address option has the following form when the addresses are 8-bit MS/TP node (link-layer) addresses.



Option fields:

Type:

1: for Source Link-layer address.

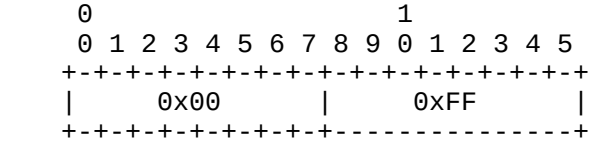
2: for Target Link-layer address.

Length: This is the length of this option (including the type and length fields) in units of 8 octets. The value of this field is 1 for 8-bit MS/TP node addresses.

MS/TP Address: The 8-bit address in canonical bit order [RFC2469]. This is the unicast address the interface currently responds to.

9. Multicast Address Mapping

All IPv6 multicast packets MUST be sent to MS/TP Destination Address 255 (broadcast) and filtered at the IPv6 layer. When represented as a 16-bit address in a compressed header (see Section 10), it MUST be formed by padding on the left with a zero:



10. Header Compression

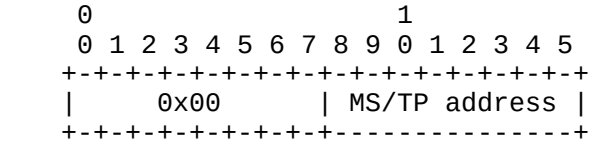
LoBAC uses LOWPAN_IPHC IPv6 compression, which is specified in [RFC6282] and included herein by reference. This section will simply identify substitutions that should be made when interpreting the text of [RFC6282].

In general the following substitutions should be made:

* Replace "6LoWPAN" with "MS/TP network"

* Replace "IEEE 802.15.4 address" with "MS/TP address"

When a 16-bit address is called for (i.e., an IEEE 802.15.4 "short address") it MUST be formed by padding the MS/TP address to the left with a zero:



11. IANA Considerations

This document uses values previously reserved by [RFC4944] and [RFC6282] and makes no further requests of IANA.

Note to RFC Editor: this section may be removed upon publication.

12. Security Considerations

The method of deriving Interface Identifiers from MAC addresses is intended to preserve global uniqueness when possible. However, there is no protection from duplication through accident or forgery.

13. Acknowledgments

We are grateful to the authors of [RFC4944] and members of the IETF 6LoWPAN working group; this document borrows extensively from their work.

14. References

14.1. Normative References

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[RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", RFC 4861, September 2007.

[RFC4862] Thomson, S., Narten, T., and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, September 2007.

[RFC4944] Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", RFC 4944, September 2007.

[RFC6282] Hui, J. and P. Thubert, "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks", RFC 6282, September 2011.

14.2. Informative References

[Addendum_an]
ASHRAE, "BSR/ASHRAE Addendum an to ANSI/ASHRAE Standard 135-2010, BACnet - A Data Communication Protocol for Building Automation and Control Networks (Advisory Public Review Draft)", September 2011, <https://osr.ashrae.org/default.aspx>.

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[RFC2469] Narten, T. and C. Burton, "A Caution On The Canonical Ordering Of Link-Layer Addresses", RFC 2469, December 1998.

[TIA-485-A]
Telecommunications Industry Association, "TIA-485-A, Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems (ANSI/TIA/EIA-485-A-98) (R2003)", March 2003.

Appendix A. Extended Data CRC [CRC32K]

This Appendix is informative and not part of the standard.

Extending the payload of MS/TP to 1501 octets requires upgrading the Data CRC from 16 bits to 32 bits. Koopman has published several papers on choosing the right CRC polynomial for the application. In [CRC32K], he surveyed the entire 32-bit polynomial space and identified some that exceed the 802.3 polynomial in performance.

The BACnet MS/TP change proposal [Addendum_an] specifies the CRC32K (Koopman) polynomial. An example C implementation is shown below. The specified use of the function is that 'crcValue' is initialized to all ones before the function is first called and, upon running the function over all octets in the payload, the ones complement of 'crcValue' be sent in LSB-first order. Upon reception, the data field and modified 'crcValue' are passed again through the function. If these fields were properly received, the result of the function will be 'CRC32K_RESIDUE'.

```
#include <stdint.h>

/* See ASHRAE 135-2010 Addendum an, section G.3.2 */
#define CRC32K_INITIAL_VALUE (0xFFFFFFFF)
#define CRC32K_RESIDUE (0x0843323B)
/* CRC-32K polynomial, 1 + x**1 + ... + x**30 (+ x**32) */
#define CRC32K_POLY (0xEB31D82E)

/*
 * Accumulate 'dataValue' into the CRC in 'crcValue'.
 * Return updated CRC.
 *
 * Note: crcValue must be set to CRC32K_INITIAL_VALUE
 * before initial call.
 */
uint32_t
CalcExtendedDataCRC(uint8_t dataValue, uint32_t crcValue)
{
  uint8_t  data, b;
  uint32_t crc;

  data = dataValue;
  crc  = crcValue;

  for (b = 0; b < 8; b++) {
    if ((data & 1) ^ (crc & 1)) {
      crc >>= 1;
      crc ^= CRC32K_POLY;
    } else {
      crc >>= 1;
    }
    data >>= 1;
  }
  return crc;
}
```

Appendix B. Consistent Overhead Byte Stuffing [COBS]

This Appendix is informative and not part of the standard.

The BACnet change proposal [Addendum_an] corrects a long-standing issue with the MS/TP specification; namely that preamble sequences were not escaped whenever they appeared in the Data or Data CRC fields. In some cases, this could result in dropped frames due to mis-alignment. The solution is encode the Data and Extended Data CRC fields before transmission using Consistent Overhead Byte Stuffing [COBS] and decode these fields upon reception.

COBS is a run-length encoding method that effectively removes '0x00' octets from its input. The worst-case overhead is bounded at approx. one octet in 254, or less than 0.5%, as described in [COBS]. An aribtrary octet value may be removed by XOR'ing the COBS output with the specified value. In the case of MS/TP, the '0x55' preamble octet is specified for removal.

Encoding proceeds logically in three passes. First, the Extended Data CRC is calculated over the data, modified for transmission as described in Appendix A, and appended to the data. The combined fields are then passed through the COBS encoder. The resulting output is then XOR'd with the MS/TP preamble octet '0x55'. The length of the encoded fields, minus two octets for compatibility with existing MS/TP devices, is placed in the MS/TP header Length field before transmission.

An example C implementation that combines these passes is shown below. The decode() function is the inverse of the encode() function.

```
#include <stdint.h>

#define MSTP_PREAMBLE_55 (0x55)

/*
 * Encodes 'length' octets of data at the location pointed to by 'input'
 * and writes the output to the location pointed to by 'output'.
 * Returns the number of octets written to 'output'.
 */
size_t
frame_encode (uint8_t *output, const uint8_t *input, size_t length)
{
  size_t code_index = 0;
  size_t read_index = 0;
  size_t write_index = 1;
  uint8_t code = 1;
  uint8_t data;
  int i;

  uint32_t crc32K = CRC32K_INITIAL_VALUE;

  while (read_index < length) {
    data = input[read_index++];
    crc32K = CalcExtendedDataCRC(data, crc32K);
    /*
     * In the common case, simply copy input to output and
     * increment the number of octets copied.
     */
    if (data != 0) {
      output[write_index++] = (data ^ MSTP_PREAMBLE_55);
      code++;
      if (code != 0xFF)
        continue;
    }
    /*
     * In the special case of encountering a zero in the input or
     * having copied the maximum number (254) of non-zero octets,
     * store the count and re-initialize encoder variables.
     */
    output[code_index] = (code ^ MSTP_PREAMBLE_55);
    code_index = write_index++;
    code = 1;
  }
  /*
   * Run the one's complement of the CRC value through the encoder,
   * LSB first.
   */
  crc32K = ~crc32K;
```

```
  for (i = 0; i < 4; i++) {
    data = ((uint8_t *) &crc32K)[i];

    if (data != 0) {
      output[write_index++] = (data ^ MSTP_PREAMBLE_55);
      code++;
      if (code != 0xFF)
        continue;
    }
    /*
     * In the special case of encountering a zero in the input or
     * having copied the maximum number (254) of non-zero octets,
     * store the count and re-initialize encoder variables.
     */
    output[code_index] = (code ^ MSTP_PREAMBLE_55);
    code_index = write_index++;
    last_code = code;
    code = 1;
  }
  /* Append a "phantom zero" to the output stream. */
  output[code_index] = (code ^ MSTP_PREAMBLE_55);
  /*
   * Return the combined value of the Data and Extended CRC fields.
   * Subtract two before use as the MS/TP frame Length field.
   */
  return write_index;
}
```

```
/*
 * Takes COBS encoded Data and Extended Data CRC fields as 'input'.
 * The 'length' contains the actual length of these fields in
 * octets (that is, the header Length field plus two).
 * Decodes the Data and Extended Data CRC fields into 'output'.
 * Returns length of decoded Data in octets.
 * Note: Safe to call with 'output' <= 'input'.
 */
size_t
frame_decode (uint8_t *output, const uint8_t *input, size_t length)
{
  uint16_t read_index  = 0;
  uint16_t write_index = 0;
  uint8_t  code, data;
  int i;

  crc32 = CRC32K_INITIAL_VALUE;
  while (read_index < length) {
    code = (input[read_index] ^ MSTP_PREAMBLE_55);
    /*
     * Sanity check the encoding to prevent the for() loop below
     * from overrunning the output buffer.
     */
    if ((read_index + code) > length)
      return 0;

    read_index++;

    for (i = 1; i < code; i++) {
      data = (input[read_index++] ^ MSTP_PREAMBLE_55);
      crc32 = CalcExtendedDataCRC(data, crc32);
      output[write_index++] = data;
    }
    if ((code < 0xFF) && (read_index < length)) {
      data = '\0';
      crc32 = CalcExtendedDataCRC(data, crc32);
      output[write_index++] = data;
    }
  }
  if (crc32K == CRC32K_RESIDUE)
    return write_index - sizeof(uint32_t);
  else
    return 0;
}
```

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