8. MAC addresses and protocol identifiers

8.1 General

The IEEE makes it possible for organizations to employ unique individual MAC addresses, group addresses, and protocol identifiers. A universal address is a MAC address that is globally unique. In addition, the IEEE has set aside a group of MAC addresses that are locally administered.

The IEEE enables globally unique addresses by assigning organizationally unique identifiers (OUIs), which are three octets (24 bits) in length. Because the assignment of the OUI in effect reserves a block of each derivative identifier (i.e., blocks of individual MAC addresses, group addresses, and protocol identifiers), the address space of the OUI is chosen to be large. Although the OUIs are 24 bits in length, their true address space is 22 bits. The LSB of the first octet can be set to one or zero depending on the application. The next-to-LSB of the first octet is zero, for all assignments. The remaining 22 bits, which shall not be changed by the assignee, result in 2^{22} (approximately 4 million) identifiers; see Figure 8.
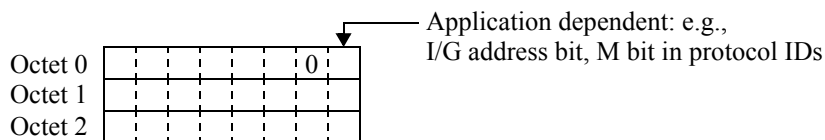

Figure 8—OUI

The universal administration of MAC addresses began with the Xerox Corporation administering Block Identifiers (Block IDs) for Ethernet addresses. Block IDs were assigned by the Ethernet Administration Office and were 24 bits in length. An organization developed addresses by assigning the remaining 24 bits. For example, the address as represented by the six octets P-Q-R-S-T-U comprises the Block ID, P-Q-R, and the locally assigned octets S-T-U.

The IEEE, because of the work in Project 802 on standardizing networking technologies, has assumed the responsibility of defining and carrying out procedures for the universal administration of these addresses. In carrying out the procedures, the IEEE acts as the registration authority for OUIs.[9] The responsibility for defining the procedures is discharged by the IEEE Registration Authority Committee (RAC), which is chartered by the IEEE Standards Association Board of Governors.

The IEEE honors the Block ID assignments made by the predecessor administration office where those assignments fall—as the great majority of them do—within the space administered by the IEEE. The Block ID is referred to as the OUI by the IEEE.

8.2 OUI

OUIs allow a general means of assuring unique identifiers for a number of purposes. OUIs are a 22-bit field assigned from a 24-bit space The IEEE Registration Authority assigns OUI values. The IEEE Registration Authority also has additional products that use the OUI assignment as its base~~in addition to other value assignments~~, e.g. OUI-36[10].

NOTE— ~~The acronym OUI is not used consistently within all IEEE standards.~~ The acronym OUI without modification is only used to refer to the 24-bit field assigned by the Registration Authority. The acronym OUI-36 is used to refer to the 36-bit field assigned by the Registration Authority. However, while not appropriate, the acronym OUI may be used to

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[9]Interested applicants should contact the IEEE Registration Authority, http://standards.ieee.org/regauth/develop/oui/index.html.

[10]More information on OUIs can be found on the IEEE Registration Authority web site, http://standards.ieee.org/develop/regauth/

refer to refer generally to all Registration Authority assignments. As a result, the use of OUI may not be consistent within all IEEE standards.

The standard representation of the OUI is as a string of three octets, using the hexadecimal representation.

8.3 Universal addresses

8.3.1 Concept

The concept of universal addressing is based on the idea that all potential members of a network need to have a unique identifier (if they are going to coexist in the network). The advantage of a universal address is that a station with such an address can be attached to any IEEE 802 network in the world with an assurance that the address is unique, if all stations adhere to the rules and that the security of the network prevents malicious spoofing of addresses. Two different lengths of the universal address have been defined, 48 bit and 64 bit.

64-bit universal addresses were introduced when it seemed that the 48-bit address space would be exhausted.in the near future. Initially, new IEEE standards projects that did not require backward compatibility with 48-bit addressing were requested to use the new 64-bit addresses. This led to some IEEE 802 standards adopting 64-bit addresses, which cannot be bridged onto IEEE 802 networks that use 48-bit addresses. The reason is that the bridging function in IEEE Std 802.1D and IEEE Std 802.1Q assume that addresses are unique among all the connected networks. Truncating a 64-bit address into a 48-bit address field can lead to two end stations having the same 48-bit address value. Instead, traffic between 64-bit and 48-bit addressed networks needs to be routed at a layer above the DLL.

NOTE—The only case in which 64-bit addresses can be bridged to a network with 48-bit addresses is the case in which the 64-bit addresses are assigned only from a 48 bit space, e.g., by assigning the last 16 bits of the 64-bit address to always be the same number.

Universal address are created from the OUI. Both values (0, 1) are assigned to the LSB of the first octet. The next-to-LSB of the first octet is set to zero; this bit of the OUI being set to zero indicates that the assignment is universal. Three-octet values occupying the same fields as OUIs can occupy, but with the next-to-LSB of the first octet set to one, are locally assigned and have no relationship to the IEEE-assigned values (as described herein).

A universal address consists of two parts: assigned by the IEEE and assigned by the assignee. The IEEE Registration Authority offers several products (e.g., OUI, OUI-36, IAB-12). They vary in the number of universal addresses the assignee can create. In the case where the IEEE assigns an OUI, tThe first 24 bits correspond to the OUI as assigned by the IEEE, except that the assignee may set the LSB of the first octet to one for group addresses or set it to zero for individual addresses. The second part, comprising the remaining 24 bits for a 48-bit address or the remaining 40 bits for a 64-bit address, is administered by the assignee. In the 48-bit MAC address, an example of which is shown in Figure 9, the OUI is contained in octets 0, 1, 2, and the value assigned by the assignee is contained in octets 3, 4, 5. This address, including its OUI, is used throughout this document as the basis for examples of MAC addresses and protocol identifiers. In the case where the IEEE assigns an OUI-36, the first 36 bits correspond to the OUI-36 as assigned by the IEEE, except that the assignee may set the LSB of the first octet to one for group addresses or set it to zero for individual addresses. The second part, comprising the remaining 12 bits for a 48-bit address or the remaining 28 bits for a 64-bit address, is administered by the assignee. In the 48-bit MAC address, an example of which is shown in Figure 9, the OUI is contained in octets 0, 1, 2_3 and the LSB nibble of octet 4, and the value assigned by the assignee is contained in the MSB nibble of octet 4 and octet 5..

NOTE—Unless mandated by backwards compatibility constraints, for example to support interworking with other IEEE 802 MAC technologies via MAC bridges, the use of 64-bit MAC addresses is preferred to the use of 48-bit MAC addresses.[11]

Hexadecimal representation: AC-DE-48-00-00-80
Bit-reversed representation: 35:7B:12:00:00:01

Octet: 0   1   2   3   4   5

            LSB   MSB   LSB   MSB   ...

            0011 0101   0111 1011   0001 0010   0000 0000   0000 0000   0000 0001

                    U/L address bit
                    I/G address bit

            |————————— OUI —————————|
        |—————————————— OUI-36 ——————————————|

                        U/L address bit
                        I/G address bit

Octet 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
Octet 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
Octet 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
Octet 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
Octet 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
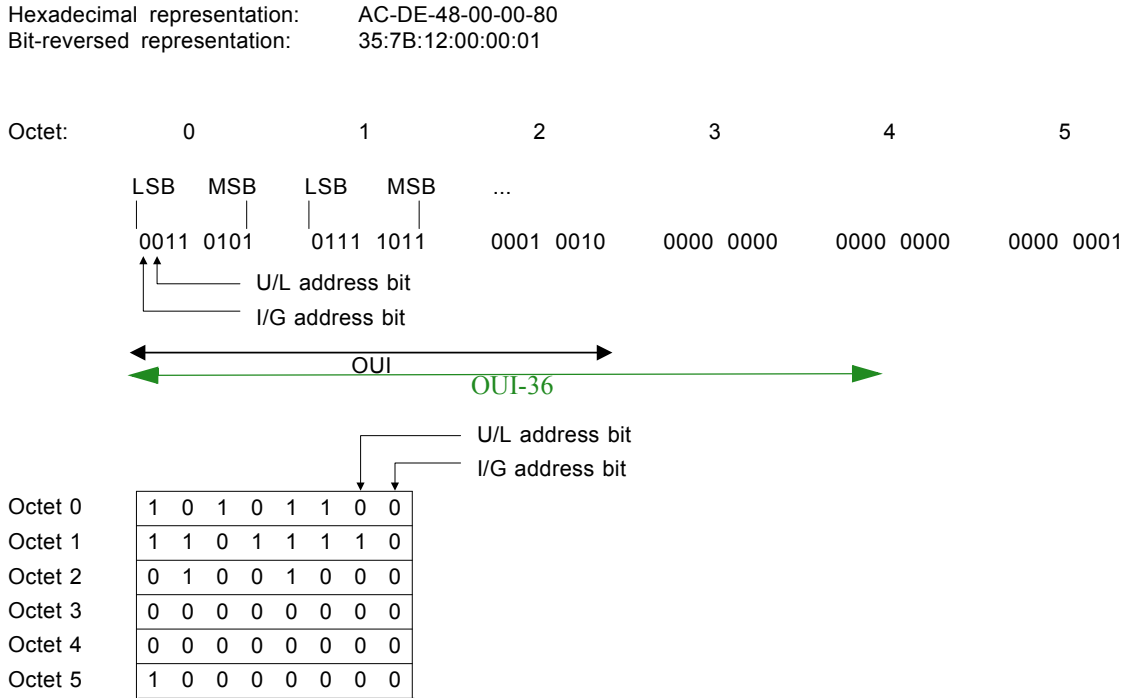Octet 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 9—48-bit universal address

An 802 network with 48-bit MAC addresses is not able to bridge to an 802 network with 64-bit MAC addresses.

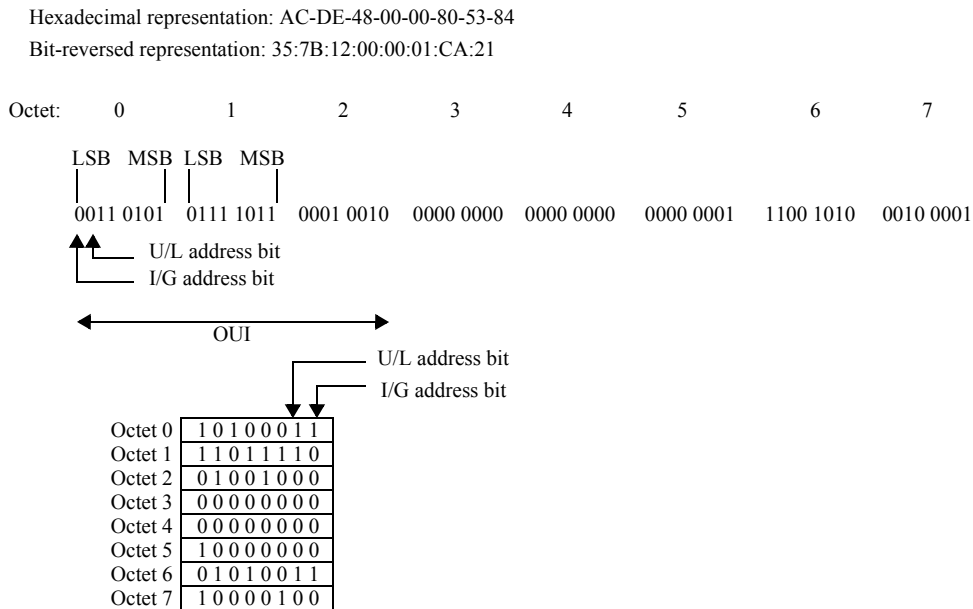An example of a 64-bit MAC address is illustrated in Figure 10.

Hexadecimal representation: AC-DE-48-00-00-80-53-84
Bit-reversed representation: 35:7B:12:00:00:01:CA:21

Octet: 0   1   2   3   4   5   6   7

          LSB   MSB LSB   MSB

          0011 0101 0111 1011 0001 0010 0000 0000 0000 0000 0000 0001 1100 1010 0010 0001

              U/L address bit
              I/G address bit

          |——————— OUI ———————|

                        U/L address bit
                        I/G address bit

Octet 0   1 0 1 0 0 0 1 1
Octet 1   1 1 0 1 1 1 1 0
Octet 2   0 1 0 0 1 0 0 0
Octet 3   0 0 0 0 0 0 0 0
Octet 4   0 0 0 0 0 0 0 0
Octet 5   1 0 0 0 0 0 0 0
Octet 6   0 1 0 1 0 0 1 1
Octet 7   1 0 0 0 0 1 0 0

Figure 10—64-bit universal address

[11]Refer to the IEEE Registration Authority, http://standards.ieee.org/develop/regauth/tut/index.html

The standard representation of a 48-bit MAC address is as a string of six octets, using the hexadecimal representation. See 8.7 for further specification relating to use of the bit-reversed representation.

NOTE—The upper, bit-stream representation of the universal address in Figure 9 shows the LSB of each octet first; this corresponds to the data-communications convention for representing bit-serial transmission in left-to-right order, applied to the model for transmission of MAC address fields (see 5.2.3). See also 8.7 for further discussion of bit-ordering issues. The lower, octet-sequence representation shows the bits within each octet in the usual order for binary numerals; the order of octet transmission is from the top downward.

The individual/group (I/G) address bit, least significant bit (LSB) of octet 0, is used to identify the destination address as an individual address or a group address. If the I/G address bit is 0, it indicates that the address field contains an individual address. If this bit is 1, the address field contains a group address that identifies one or more (or all) stations connected to the IEEE 802 network. The all-stations broadcast address is a special, predefined group address of all 1's.

The universally or locally administered (U/L) address bit is the bit of octet 0 adjacent to the I/G address bit. This bit indicates whether the address has been assigned by a local or universal administrator. Universally administered addresses have this bit set to 0. If this bit is set to 1, the remaining 46 bits (i.e. all bits except the I/G and U/L bits) have been locally administered.

8.3.2 Assignment by organizations

Varying the last 24 bits in the block of MAC addresses for a given OUI allows the OUI assignee approximately 16 million unique individual addresses and 16 million unique group addresses that no other organization may assign (i.e., universally unique). The IEEE intends not to assign additional OUIs to any organization unless the organization has exhausted this address block. Therefore, it is important for the IEEE to maintain a single point of contact with each assignee to avoid complicating the assignment process. It is important to note that in no way should these addresses be used for purposes that would lead to skipping large numbers of them (for example, as product identifiers for the purpose of aiding company inventory procedures). The IEEE asks that organizations not misuse the assignments of the last 24 bits and thereby unnecessarily exhaust the block. There are sufficient identifiers to satisfy most needs for a long time, even in volume production; however, no address space is infinite.

The method that an assignee uses to ensure that no two of its devices carry the same address will, of course, depend on the assignment or manufacturing process, the nature of the organization, and the organization's philosophy. However, the users of networks worldwide expect to have unique addresses. The ultimate responsibility for assuring that user expectations and requirements are met, therefore, lies with the organization offering such devices.

8.3.3 Uniqueness of address assignment

An issue to be considered is the nature of the device to which uniqueness of address assignment applies.

The recommended approach is for each device associated with a distinct point of attachment to an IEEE 802 network to have its own unique MAC address. Typically, therefore, an IEEE 802 network adapter card (or, e.g., an equivalent chip or set of chips on a motherboard) should have one unique MAC address for each IEEE 802 network attachment that it can support at a given time.

NOTE—It is recognized that an alternative approach has gained currency in some implementations, in which the device is interpreted as a complete computer system, which can have multiple attachments to different networks. Under this interpretation, a single MAC address is used to identify all of the system's points of attachment to the networks in question. This approach, unlike the recommended one, does not automatically meet the requirements of IEEE Std 802.1D MAC bridging.

8.4 Local addresses

Local addresses are MAC addresses for which there is no guarantee that the address is unique in all 802 networks. Local addresses may be assigned any value that has the U/L bit set to indicate a local addresses. Local addresses need to be unique on a LAN or bridged LAN unless the bridges support VLANs with independent learning.

8.5 Protocol identifiers

Clause 9 specifies the SNAP, which permits multiplexing and demultiplexing of private and public protocols, as described in 9.1, among multiple users of a data link. An organization that has an OUI assigned to it may use its OUI to assign universally unique protocol identifiers to its own protocols, for use in the protocol identification field of SNAP PDUs, as described in 9.3.

The protocol identifier is five octets in length and follows the LLC header in a frame. The first three octets of the protocol identifier consist of the OUI in exactly the same fashion as in 48-bit MAC addresses. The remaining two octets are administered by the assignee. In the protocol identifier, an example of which is shown in Figure 11, the OUI is contained in octets 0, 1, 2 with octets 3, 4 being assigned by the assignee of the OUI.

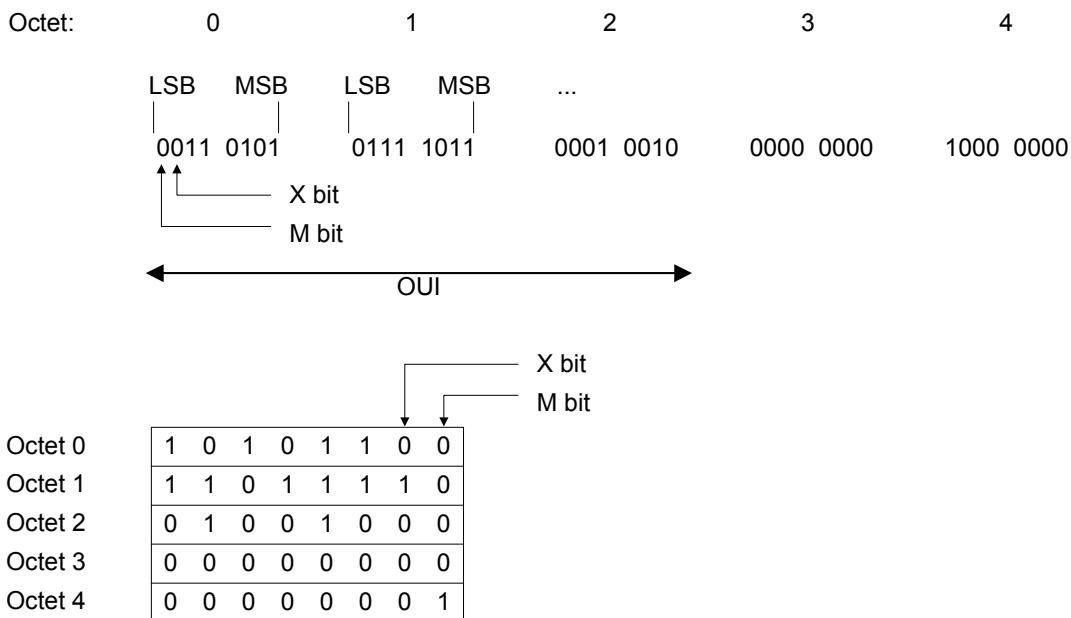Hexadecimal representation: AC-DE-48-00-80

Figure 11—Protocol identifier

The standard representation of a protocol identifier is as a string of five octets using the hexadecimal representation.

The LSB of the first octet of a protocol identifier is referred to as the M bit. All identifiers derived from OUIs assigned by the IEEE shall have the M bit set to zero. Values with the M bit set to one are reserved.

Protocol identifiers may be assigned universally or locally. The X bit of a protocol identifier is the bit of the first octet adjacent to the M bit. All identifiers derived from OUIs assigned by the IEEE will have the X bit

set to zero and are universally assigned. Values with the X bit set to one are locally assigned and have no relationship to the IEEE-assigned values. They may be used, but there is no assurance of uniqueness.

8.6 Standard group MAC addresses

The previous subclauses described the assignment of individual and group MAC addresses, and protocol identifiers for public or private use by private organizations. There is also a need for standard group MAC addresses to be used with standard protocols. The administration of these addresses, including the procedure for application and a list of currently assigned values, is described on the web pages for the IEEE Registration Authority[12]. These standard group MAC addresses come from a block of universally administered MAC addresses derived from an OUI that has been assigned by the IEEE for this purpose.

8.7 Bit-ordering and different MACs

Throughout this subclause, considerations relating to the order of bit and/or octet transmission refer to the basic bit-serial model of transmission that applies to the representation of MAC frames at the boundary between the MAC   and the PHY, as described in 5.2.3.

8.7.1 General considerations

The transmission of data on IEEE Std 802.3 networks is represented, as described in 5.2.3, as occurring LSB first within each octet. This is true for the entire frame: MAC address fields (source and destination), MAC-specific fields (e.g., length field), and the MAC Information field.

On some other network types, each octet of the MAC Information field is represented as being transmitted most significant bit (MSB) first. The MAC address fields (source and destination), however, are represented as being transmitted with the LSB of each octet first. Thus, the first bit transmitted is the I/G address bit, as in IEEE Std 802.3 networks. For frames that originate within the MAC (e.g., MAC-embedded management frames), the ordering of bits within the MAC Information field is defined by the MAC specification.

For most purposes, the difference in the bit-orderings used to represent transmission of the octets of the MAC Information field is of no consequence, whether considered within a given MAC type, or across different MAC types. Each octet of user data is mapped to and from the appropriate ordering, symmetrically by the transmitting and receiving MAC entities. An unfortunate exception has occurred, however, where the octets concerned are those of a MAC address that is embedded, as user data, in the MAC Information field.

Subclause 8.7.2 describes the problem with different bit-orderings and some of the issues arising from it. Subclause 8.7.3 provides a recommendation for the development of new protocols.

8.7.2 Illustrative examples

This subclause illustrates the various bit- and octet-transmission scenarios that can occur, and it is intended as a basis for clarifying the issue of bit-ordering for MAC addresses across different MACs. Throughout, the examples make use of the OUI value AC-DE-48, introduced in 8.3.1. This three-octet value is considered in its two possible roles: as the first part of a five-octet protocol identifier, and as the first part of a six-octet MAC address. The consistent representations of the OUI in its role as part of a protocol identifier are contrasted with the sometimes variable representations that apply to its role as part of a MAC address.

NOTE—Protocol identifiers always form part of the normal user data in a MAC Information field; hence, there is nothing special about OUI octets in their protocol identifier role.

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[12]http://standards.ieee.org/develop/regauth

For the examples, the bit significance of an OUI in general is defined to be as in Figure 12.

```
            MSB                  LSB
  Octet 0    h  g  f  e  d  c  b  a
  Octet 1    p  o  n  m  l  k  j  i
  Octet 2    x  w  v  u  t  s  r  q
```

When used in LAN MAC addresses:
Bit "a" of the OUI = I/G address bit.   Bit "b" of the OUI = U/L address bit.

When used in protocol identifiers:
Bit "a" of the OUI = M bit.   Bit "b" of the OUI (always zero) = X bit.

Figure 12—Bit significance of an OUI

When transmitted on a network with all data octets of the OUI transmitted LSB first, the OUI portions of a protocol identifier and of a MAC address appear as in Figure 13. When transmitted on a network with the data octets of the OUI transmitted MSB first, the OUI portions of a protocol identifier, and of a MAC address contained in a MAC Address field, appear as in Figure 14.
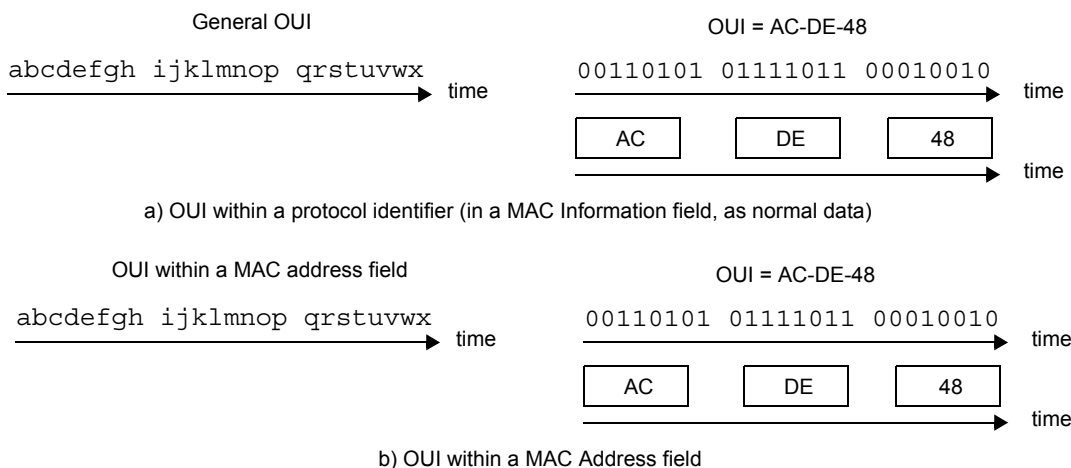
General OUI   OUI = AC-DE-48

```
abcdefgh ijklmnop qrstuvwx              00110101 01111011 00010010
                            time                                      time
```

```
                                         [  AC  ]   [  DE  ]   [  48  ]
                                                                      time
```

a) OUI within a protocol identifier (in a MAC Information field, as normal data)

OUI within a MAC address field   OUI = AC-DE-48

```
abcdefgh ijklmnop qrstuvwx              00110101 01111011 00010010
                            time                                      time
```

```
                                         [  AC  ]   [  DE  ]   [  48  ]
                                                                      time
```

b) OUI within a MAC Address field

Figure 13—Order of bit and octet transmission for an OUI with LSB transmitted first

In some circumstances, it is necessary to convey MAC addresses as data within MAC Information fields, e.g., as part of a management protocol or a network layer routing protocol.

For network types in which Figure 13 applies, such as IEEE Std 802.3, the bit-ordering within the octets of a MAC address conveyed as data is the same as both the ordering when the address appears in a MAC address field and the ordering for octets of nonaddress information.

For network types in which Figure 14 applies there appears to be a choice of representations for MAC addresses conveyed as data, as follows:

— Canonical format: The octets of the MAC address can be treated like any other data octets and transmitted with the bit-ordering of Figure 14(a). The canonical format is illustrated in Figure 15.

— Noncanonical format: The bit-ordering of Figure 14(b) is treated as a property of the MAC address rather than of the MAC address field as transmitted in MAC frames, and the MAC address octets
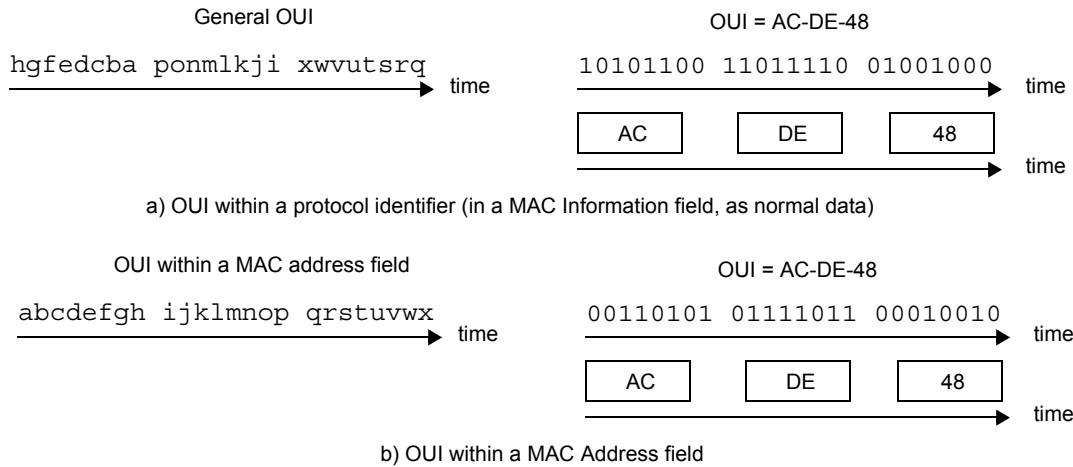
General OUI

OUI = AC-DE-48

`hgfedcba ponmlkji xwvutsrq` → time

`10101100 11011110 01001000` → time

| AC | DE | 48 | → time

a) OUI within a protocol identifier (in a MAC Information field, as normal data)

OUI within a MAC address field

OUI = AC-DE-48

`abcdefgh ijklmnop qrstuvwx` → time

`00110101 01111011 00010010` → time

| AC | DE | 48 | → time

b) OUI within a MAC Address field

Figure 14—Order of bit and octet transmission for an OUI with MSB transmitted first

General OUI

OUI = AC-DE-48

`hgfedcba ponmlkji xwvutsrq` → time

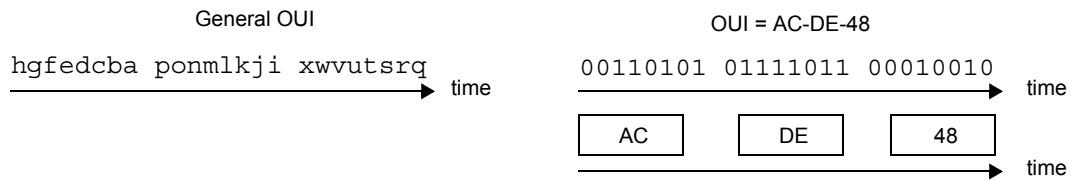`00110101 01111011 00010010` → time

| AC | DE | 48 | → time

Figure 15—Order of bit and octet transmission for an OUI in a MAC address with MSB transmitted first, canonical format.

can be transmitted with the bit-ordering reversed compared with normal data octets. The noncanonical format is illustrated in Figure 16.

General OUI

OUI = AC-DE-48

`abcdefgh ijklmnop qrstuvwx` → time

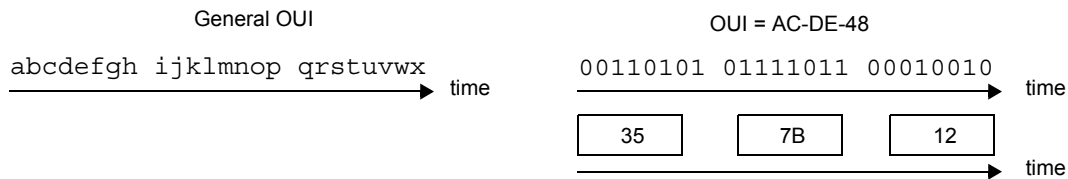`00110101 01111011 00010010` → time

| 35 | 7B | 12 | → time

Figure 16—Order of bit and octet transmission for an OUI in a MAC address with MSB transmitted first, noncanonical format.

The noncanonical format has the unfortunate consequence that applications operating in environments containing a mixture of LAN types have to handle different representations of MAC addresses, according to the environment in which the MAC address is to be used.

In Figure 13, Figure 14, Figure 15, and Figure 16, it can be seen that the interpretation of OUI bits as octet values is consistent. This reversal of the bit order applies only to all six octets (not just the OUI) of a MAC address placed in the MAC Information field of a frame by a protocol that uses the bit-reversed view of MAC addresses derived from Figure 14(b). Frames containing, or possibly containing, such MAC addresses are described as having noncanonical format. Frames that cannot contain such MAC addresses are described as having canonical format.

Note that there is no way of knowing, from MAC layer information only, whether a particular frame is in canonical or noncanonical format. In general, this depends on which higher layer protocols are present in the frame.

8.7.3 Recommendation

Designers of protocols that operate above the DLL are strongly recommended to avoid specifying new protocols that result in frames of noncanonical format.