MACsec hops

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MAC Security (MACsec) cryptographically protects frames on a hop-by-hop basis. IEEE Std 802.1AE describes a number of use cases, and specifies the position of the MACsec shim in interface stacks and the necessary control plane addressing for each case. When traversing a provider bridged or provider backbone bridged (PBN or PBBN) network, a ‘single hop’ can be supported by a number of intervening bridges. This note explains why these bridges can be treated as a ‘single hop’, why the restriction to hop-by-hop operation is important, and how to deal with some additional cases. It has been written mainly for an audience that is not familiar with the original development of both MACsec and other 802.1 protocols, but would like to explore additional possibilities.

1. Overview

Ignoring MACsec’s hop-by-hop design would allow additional uses of the MACsec protocol[1]. However a narrow protocol-centric view of the possibilities risks setting aside data rate, control plane performance, and interoperability considerations, and does not take into account the security risks or the existence, needs, and evolution of other network protocols. This note explains why IEEE 802.1AE–2006[2] does not include multi-hop possibilities that might appear ‘interesting’ at first glance, and why it may prove difficult to procure equipment that uses MACsec in such custom configurations. It also describes additional use cases that support or exploit more recent developments in IEEE 802.1 bridging technology.

The ‘single hop’ restriction is a result of adopting a coherent approach to the considerations alluded to above, more specifically:

a) MACsec protects all frames transmitted and received by authenticated and authorized protocol participants, ensuring that network operation is not compromised by unauthorized modifications or additions (3).

b) The communicating MACsec peers that cryptographically protect and validate any given frame have to operate on the same frame fields, and the same frame field data. Modification of any frame field has the potential to disrupt network operation[3], so the entire frame (including the addresses, protocol types, and header data) has to be protected and validated (3).

c) The use of MACsec should be possible (and useful) when authenticated and authorized bridges add or remove tags, or make permitted changes to frame fields, such as the Priority Code Point and Drop Eligible Indicator in the VLAN tag.

d) Performing MACsec processing naturally involves accessing and (if confidentiality protection is being provided) encrypting packet data. To avoid the cost of additional memory bandwidth it is desirable to locate the MACsec processing within chips/modules that are already concerned with moving the data, such as network interfaces (4.1).

e) Achieving the necessary data rates at reasonable cost limits the number of SAKs (the secret keys used to protect data) used at any one time (4.1).

f) Network control plane protocol performance should not be impacted by MACsec. Specifically, it should not be necessary to agree and install fresh SAKs if the network paths are reconfigured (4.2).

Each of these points is discussed in detail below. Section 2 provides a brief review of fundamental architectural concepts, Section 3 discusses the security threats MACsec has to handle, and Section 4 how connectivity is secured. Additional use cases are presented in Section 5. Section 6 contains some ideas for improvements to the standards, and Annex A and Annex B provide space for FAQs and durther technical detail respectively.

[1] Or derivative and similar protocols. Past proposals have commonly suggested that a single protection operation extend over multiple hops so that MACsec capability/compatibility can be claimed for existing bridges without the need to develop or deploy MACsec upgrades for those bridges.

[2] See IEEE 802.1AE-2006 7.3.2, and in particular NOTE 1 and NOTE 2 in that clause.

[3] Beyond the very limited impact of simply causing the frame to be lost.

2. Bridging architecture

A brief review of architectural concepts[4] follows, as an aid to our subsequent examination of detailed scenarios that illustrate what MACsec (and possible alternatives) can and cannot do well.

2.1 Layering and the ISS

Layered protocol entities communicate with their peer or peers using the service provided by the protocol entities in the layer below. We are really concerned with just one service—the MAC Internal Sublayer Service (ISS)[5].

Each and every bridge's job can be summarized as supporting one or more instances of the ISS, with the desired efficiency/extent/manageability/etc. Each instance provides connectivity[6] between a set of end stations and/or bridges. At the lowest layer, in end stations or intermediate systems (bridges), the ISS is mapped to (provided using) the particular media access method supported by the physical LAN. Each bridge concatenates two or more instances of the ISS. Some bridges, Provider Edge Bridges (PEBs) and Backbone Edge Bridges (BEBs) for example, include protocol entities whose explicit function is to provide one instance of the ISS over another. The protocol entities of others (Provider Bridges, for example) are configured to relay all the frames transmitted by others (Customer Bridges, in this example) so what the latter see as a single instance of the ISS is supported by two or more instances concatenated at a lower (sub-)layer.

Virtual LANs (VLANs) are really just a way (using a VLAN tag field added to each frame) of separating multiple instances of the ISS. The EISS (Enhanced Internal Sublayer Service) used by VLAN-aware bridging components is a compact way of describing that multiplexing at a service interface. An EISS service access point functions just as a number (potentially 4094) of ISS service access points in parallel[7]. Similarly the MAC address encapsulation provided by Backbone Edge Bridges separates and provides address independence between a higher and lower layered instances of the ISS.

The layered architecture of a Bridge is often drawn as in Figure 1. This shows the bridge's MAC Relay entity below the level of the MAC Service used by higher layer protocols (supported by LLC) in the end stations to the left and right—emphasizing the fact that the relay is transparent to those service users. For our present purposes it is more convenient to use diagrams that show the interface stacks supporting relay and higher layer entities in more detail (e.g. Figure 2).

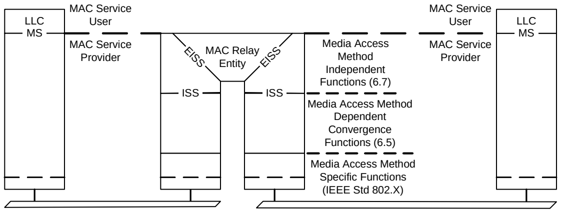

LLC
MS
MAC Service User
MAC Service Provider
EISS
MAC Relay Entity
EISS
ISS
ISS
Media Access Method Independent Functions (6.7)
Media Access Method Dependent Convergence Functions (6.5)
Media Access Method Specific Functions (IEEE Std 802.X)
MAC Service User
MAC Service Provider
LLC
MS

Figure 1—A VLAN bridge and end stations

2.2 Systems, networks, and components

Many protocols have been specified purely from the point of view of the rules governing the interaction of entities whose sole function is to provide the protocol (or worse by describing only the frame formats and—just possibly—individual field processing), thus assuming that the relationship between those protocol entities and the rest of the system is obvious.

In a layered system or network where the intent is often to provide or extend a service transparently (leaving the interactions between individual service users unchanged while increasing network throughput, physical extent, or the number of users) the same protocols can be used at many different layers. So can protocols and entities (such as those adding and removing VLAN tags) that are not truly transparent but serve to select between different instances of transparent service. For a standard to be useful—promoting the availability of equipment and interoperability between items of equipment developed by different organizations—it has to specify (or at least suggest) the layering relationship between (and concomitant configuration aspects of) protocol entities.

When very similar functions have to be performed at different sub-layers it is more useful to re-use an existing protocol entity than to invent a new one, and the same applies to entire combinations of protocol

[4] The architectural concepts and terms are described in some detail in IEEE Std 802.1X Annex D.

[5] The service provided by a LAN, stripped of the peculiarities introduced by one or other media access methods, but with the explicit inclusion of parameters necessary for describing the process of forwarding the frame—which might otherwise be thought particular to the way the service is provided, and not of concern to upper layers in the end stations using the MAC Service.

[6] IEEE Std 802.1AE and 802.1X-2010 Annex D.8 formalizes this notion as a Connectivity Association (CA), following RFC 787.

[7] IEEE Std 802.1Q specifies trivial protocol entities that can be used to split/recombine an EISS interface into/from component ISS interfaces so that other protocol entities specified just for use with the latter can be used without respecification. Note that PBBN technology allows many more than 4094 VLANs to be supported by a single network, while still allowing each service instance to be explicitly identified (by the ISID).

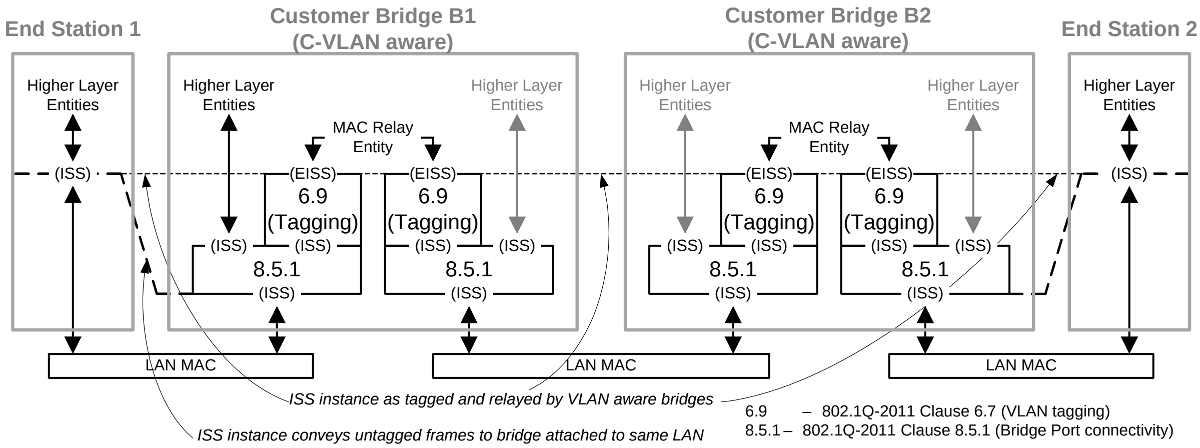

End Station 1
Customer Bridge B1 (C-VLAN aware)
Customer Bridge B2 (C-VLAN aware)
End Station 2
Higher Layer Entities
MAC Relay Entity
(ISS)
(EISS)
6.9 (Tagging)
8.5.1
LAN MAC
ISS instance as tagged and relayed by VLAN aware bridges
ISS instance conveys untagged frames to bridge attached to same LAN
6.9 – 802.1Q-2011 Clause 6.7 (VLAN tagging)
8.5.1 – 802.1Q-2011 Clause 8.5.1 (Bridge Port connectivity)

Figure 2—Interface stacks for VLAN-aware bridges and end stations

entities. The functionality of a Provider Edge Bridge is (for example) conveniently expressed (see Figure 3) as the concatenation of (a number of) C-VLAN aware components with an S-VLAN aware component, each of these internal system components having functionality that could be instantiated in separate systems (compare the left and right sides of Figure 3).[8] Part of the strength of this component based design is its natural inheritance and preservation of the essential arrangements for protocols that are not the immediate focus of the designer.

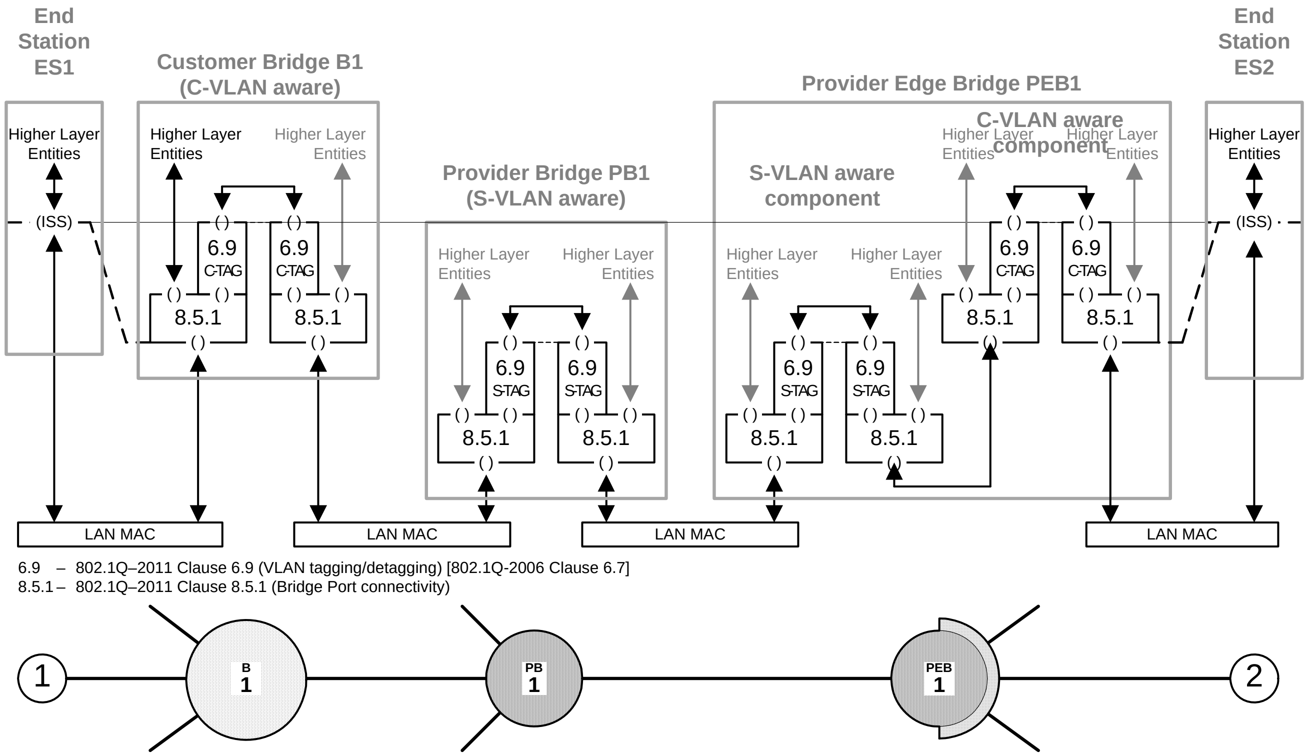

End Station ES1
Customer Bridge B1 (C-VLAN aware)
Provider Bridge PB1 (S-VLAN aware)
Provider Edge Bridge PEB1
S-VLAN aware component
C-VLAN aware component
End Station ES2
Higher Layer Entities
(ISS)
( )
6.9
C-TAG
S-TAG
8.5.1
LAN MAC
6.9 – 802.1Q–2011 Clause 6.9 (VLAN tagging/detagging) [802.1Q-2006 Clause 6.7]
8.5.1 – 802.1Q–2011 Clause 8.5.1 (Bridge Port connectivity)
1
B 1
PB 1
PEB 1
2

Figure 3—Interface stacks for a path through a Provider Bridged Network

The lower part of Figure 3 is a plan diagram of the connectivity between the systems and their components. This view 'from above' serves to emphasize that the interface stack picture is best at showing a single path, and that other end to end paths can join and share part of this path. In some cases it is

[8] There was some initial reluctance to follow this approach—a fear that it would mandate more functionality than necessary—but experience has shown its value. Some functionality that was initially explicitly removed has had to be reinstated to address real needs, and it is now a useful way of specifying new functionality, and of actually providing that functionality by interconnecting appropriately configured systems that are already available—rather than requiring custom engineering that might prove uneconomic in cases where relatively few systems are required.

convenient to restrict the properties of one of the system components (requiring a component to serve a single customer, or to only have two ports, for example). Such a restriction permits some adjustment of the way that configuration protocols are supported by the system.

2.3 Connectivity and address scopes

In general, a configuration protocol needs to know its immediate peer neighbours in a network, and to be able to transmit and receive particular frames to and from those neighbours, while the same frames should not reach more distant participants in the protocol[9]. When different instances of the same protocol is to be deployed at different layers within the architecture, the set of protocol entity peers for each protocol instance naturally differs, and has to be kept separate. This separation is enforced by using different destination MAC addresses for each protocol instance. Specific group MAC addresses are used for this purpose—it is either impossible or impractical to manually configure the individual addresses of each entity's peers before protocol operation begins. This use of group addresses is a general feature of LAN-based protocols, but the use of reserved group addresses that are always filtered by particular types of bridges is specific to the layered architecture of bridged networks.

Each MAC Relay entity includes a Filtering Database (FDB). FDB entries are used to ensure that frames with given destination MAC addresses (or given combinations of MAC address and VLAN ID) are not forwarded. FDB entries can be created by management, by the operation of network configuration protocols (such as ISIS-SPB), or by learning the (relative) location of bridges by observing the source MAC addresses of frames. Permanent FDB entries are made for the Reserved Addresses used by protocol entities to discover their peers (at the appropriate layer), see Table 1 and Figure 4.

Table 1—Reserved addresses for bridge components

Value	Assignment	Filtered by		
		C-[1]	S-B-[2]	T-
01-80-C2-00-00-00	Bridge Group Address, Nearest Customer Bridge group address[3]	Y		
01-80-C2-00-00-01	IEEE MAC-specific Control Protocols group address	Y	Y	Y
01-80-C2-00-00-02	IEEE Std. 802.3 Slow_Protocols_Multicast address	Y	Y	Y
01-80-C2-00-00-03	Nearest non-TPMR Bridge group address[4]	Y	Y	
01-80-C2-00-00-04	IEEE MAC-specific Control Protocols group address	Y	Y	Y
01-80-C2-00-00-05 01-80-C2-00-00-06	Reserved for future standardization - media access method specific	Y	Y	
01-80-C2-00-00-07	Metro Ethernet Forum ELMI protocol group address[5]	Y	Y	
01-80-C2-00-00-08	Provider Bridge Group Address	Y	Y	
01-80-C2-00-00-09 01-80-C2-00-00-0A	Reserved for future standardization	Y	Y	
01-80-C2-00-00-0B 01-80-C2-00-00-0C	Reserved for future standardization	Y		
01-80-C2-00-00-0D	Provider Bridge MVRP Address	Y		
01-80-C2-00-00-0E	Individual LAN Scope group address, Nearest Bridge group address[6]	Y	Y	Y
01-80-C2-00-00-0F	Reserved for future standardization	Y		

[1] Filtered by C-VLAN aware components in Customer Bridges and Provider Edge Bridges, and by VLAN-unaware MAC Bridges (IEEE 802.1D).
[2] B-components (in Backbone and Backbone Edge Bridges) behave exactly as S-components (in Provider and Provider Edge Bridges). The MAC address encapsulation provided by PEBs separates the address spaces for these components.
[3] As stated in 802.1Q-2011 (clause 13.39, and Table 8-1) a C-VLAN component (within a Provider Edge Bridge) that relays frames from a single Customer Edge Port to a single Provider Edge Port (see 802.1Q-2011 clause 15.4) may forward (not filter) frames with this destination address.
[4] Also know as the 'PAE group address' in 802.1X-2010, which recommends its use as the default for the PAE's EAPOL clients and the KaY.
[5] This address is not exclusively reserved for this purpose; other uses are reserved for future standardization.
[6] It is intended that no IEEE 802.1 relay device will be defined that will forward frames that carry this destination address. Protocol uses include controlling Power over Ethernet.

[9] The protocol might need to transmit frames that reach all participants in a particular instance of the protocol as well. In this case they are all treated as neighbours.

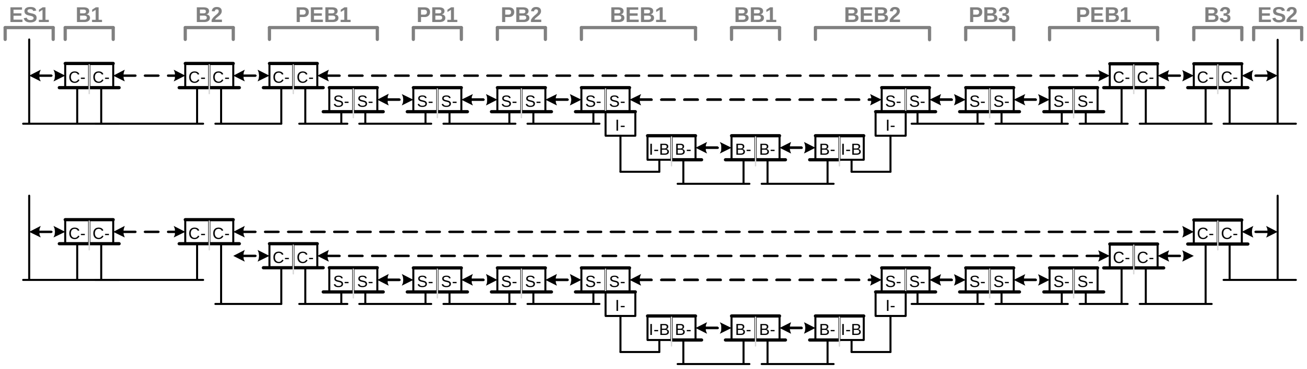


Figure 4—Address scopes in a Bridged Local Area Network

Figure 4 depicts a cross-section through a Bridged Local Area Network, using a simplified interface stack diagrams to illustrate the various address scopes provided by Table 1. TPMRs (Two Port MAC Relays) and the corresponding scope (bounded by the limits of real physical media and not passing through any bridge component) are not shown. Two sets of interface stacks are shown, with the lower depicting the additional scope that can be provided if the C-VLAN components of the Provider Edge Bridges forward the Nearest Customer Bridge group address (see footnote 3 to Table 1). Backbone Edge Bridges (BEBs) do not currently support a similar scope for the directly attached Provider Bridges (PBs), and this could be consider a deficiency of the current standards since BEBs are necessarily administered by the backbone network provider while the Provider Bridges might well be administered by an entirely separate organization.

3. Security threats and requirements

As 802.1AE-2006 says in its opening paragraph:

“IEEE 802® Local Area Networks (LANs) are often deployed in networks that support mission-critical applications. These include corporate networks of considerable extent, and public networks that support many customers with different economic interests. The protocols that configure, manage, and regulate access to these networks typically run over the networks themselves. Preventing disruption and data loss arising from transmission and reception by unauthorized parties is highly desirable, since it is not practical to secure the entire network against physical access by determined attackers.”

and (later in 1.1 Introduction):

“MACsec protects communication between trusted components of the network infrastructure, thus protecting... network operation. MACsec cannot protect against attacks facilitated by the trusted components themselves, and is complementary to, rather than a replacement for, end-to-end application-to-application security protocols. The latter can secure application data independent of network operation, but cannot necessarily defend the operation of network components, or prevent attacks using unauthorized communication from reaching the systems that operate the applications.”

Thus, although MACsec can provide confidentiality and data origin authenticity, it has more to do than just hiding the data transmitted and received on behalf of network users from prying eyes. Indeed, because end-to-end transmission is usually supported by IP, there is no way that security at or just above the MAC layer could ensure that user data is accessed by only the original transmitter and the final receiver.

A significant motivation for the standardization of MACsec was the desire to avoid the need to design a protocol-specific security mechanism for each and every protocol used as part of network control and configuration. It can be readily appreciated that such a protocol-specific security approach would most likely lead to a delay in the development of the necessary protocols, or in forcing a choice on every network designer between being able to use the latest (but insecure) or secure (but older) technology.[10] Satisfying the desire for MACsec to be capable of protecting all our MAC layer control protocols, including those yet to be designed, without serial development or deployment delays imposes additional requirements:

- the MACsec specification itself needs to remain unchanged when it is to be incorporated into a new type of system (or network);
- the specification of the new system needs to naturally provide the right interfaces and opportunities for the addition of MACsec, even if no thought has been given to the subject by the system's designers;
- existing MACsec capable systems, within the network or available off the shelf, should not require modification to operate in a network with the new control protocols or systems unless they explicitly need to use the new protocols.

One consequence of the above is that MACsec needs to protect all the traffic transmitted and received on a given LAN, if the traffic is to be protected at all. A more or less general way might be devised to subset this protection (identifying those protocols that do have their own security mechanisms and skipping protection for those frames, for example) but would not reduce the frame protection and validation performance requirements (high throughput, very low delay) since such frames constitute a very low percentage of the potential load.

The point has to be made that if (as is the case for the vast majority of bridges[11]) a bridge learns from the source MAC address of forwarded frames, then each frame forwarded is de facto a control frame, potentially altering the configuration of the network, as well as being a data frame. If such frames are not validated by the forwarding bridge, an attacker with LAN access can selectively deny service by transmitting frames (with a source address that is being used by legitimate traffic) on the 'wrong' LAN. A crude DoS attack, aimed at simply denying all service and possibly carried out by sending large number of frames to overwhelm a switch's control processor, might be easily detected, but a learning attack offers more possibilities. The attacker might, for example, attack a source only when it transmitted frames secured by IPsec (or some other protocol) and thus persuade the frustrated user to turn security off.

NOTE—This attack could be carried out with frames with an Ethertype reserved for an 'end-to-end' authentication protocol if individual LANs on the path are not secure—existing bridges will (and should) learn from the source addresses of such frames.

While MACsec cannot protect end-to-end if IP routers lie along the path, the requirement is often to protect only part of the path—even if each end uses the MAC address of the other directly as the destination in the frames it transmits. If part of the path is known to be physically secure (within a cage in a co-location facility, for example) there is no particular need to require MACsec capability on the end equipment (which might be a router without MACsec capability, for example). In such cases there is a positive requirement to protect only those LANs in the path that an attacker might be able to access[12]. In general a network might comprise a number of trusted regions, each under the secure control of a single administration, connected by LANs or LAN services (such as provider bridged network) that may be controlled by a different administration and that are not (or are not trusted to be) physically secure. Requirements naturally arise to secure particularly exposed LANs in any network, to authenticate and secure connectivity between different administrations, or to secure connectivity 'end-to-end' where the ends are those of a path provided by a subcontracted administration and each 'end' of that path lies within equipment administered by the same organization—be that the organization providing the connectivity or the organization using it. IEEE 802.1AE–2006 Figure 11–12 provides some examples.

In the main the technical requirement for MAC security discussed here is for integrity protection (a frame that passes validation checks on reception has not been modified since its transmission), and for data origin authentication (the frame was originally transmitted by an authenticated peer)[13]. However the general perception of security is one of confidentiality, so no security standard can be without it.

There will of course be cases where confidentiality is really required, and where IPsec may be impractical

[10] This would mirror the early experience of those wishing to use MIBs as part of operational practice (i.e. to really manage their networks) in an era of MIB development as a separate arcane skill, quite separate from the rest of system and network protocol design. Under these conditions MIB development only starts when everything else is almost complete—ensuring that the first release product is only fully manageable through the console interface.

[11] Backbone Bridges that only support PBB-TE or that only support shortest path operation using ISIS-SPB would be an exception, but even in a backbone one or two B-VLANs are likely to be dedicated to providing local management connectivity or other services that use station location learning. Even in 'exclusively routed' networks learning bridges (switches) can be found, playing a valuable (if largely transparent) role expanding interface port counts etc.

[12] This definite requirement has been a problem for proposed layer 2 and-to-layer 2 end schemes, such as the (never deployed and now withdrawn) 802.10 'interoperable LAN security'. In that standard bridges that sought to terminate the scope of protection on a path had to acquire the (secret) cryptographic keys from the end stations that authenticated their mutual communication, with the burden of a large number (potentially thousands) of keys in bridges that connected trusted and untrusted regions of the network. These keys might have to be acquired in a hurry if a network reconfiguration resulted in end to end paths traversing different bridges.

[13] In the case of group communication—as with multicast on shared media—by one of a number of authenticated peers.

(?), cannot be applied until later in the envisaged transaction (?), or has significantly worse price/performance in a particular scenario. In some cases confidentiality is far more important than delivery (if the network itself is under attack the user will choose other means of delivering data) or the operation of the network is the responsibility of a separate organization, and is secured independently of the user data conveyed. Such cases are discussed later in this note.

4. Securing connectivity

This section discusses how connectivity is to be secured, given the bridging architecture, systems, and networks (2. above), and the threats and requirements (3. above). It reviews relevant aspects of the available cryptographic technology (4.1), particularly the use of secret keys, before considering how those keys are to be used to protect frames (4.2), and how such protection is to be included within the network and system architecture (4.3).

4.1 Cryptographic technology

At the data rates of interest, from a few megabits per second to hundreds of gigabits or even terabits per second, the only feasible security is provided by per frame symmetric (secret) key cryptography. This uses a block cipher together with a 'mode' of operation that allows the successive use of that block cipher to protect variable length data (such as a frame or packet). IEEE 802.1AE and 802.1X have been deliberately designed to allow the addition of Cipher Suites (each specifying MACsec's use of a block cipher and mode) to take advantage of future developments in cryptography. At present all conformant Cipher Suites use the AES block cipher and the GCM (Galois Counter Mode)[14] as documented by NIST. The crucial characteristic of GCM is that it is relatively efficient and parallelizable, enabling high throughput implementation (to and above 100 Gb/s).

AES does not use the secret key directly, but expands it into a number of keys, one for each round[15]. Eleven round keys are needed for 128-bit encryption, and fifteen for 256-bit. High performance GCM–AES implementations store[16] the round keys for each secret key in active use, rather than recomputing them for each protected message. Thus, when a GCM–AES implementation has to authenticate (and possibly decrypt) a received frame, it needs rapid access to more data than is carried in a minimum sized Ethernet frame. The fact that it is neither desirable nor practicable to control (either on transmission or reception) which of the currently in-use secret keys will be required by the next frame places a high premimum on keeping the maximum number of such keys low. If the number is sufficiently low, all secret-key and other secure association specific data can be kept with the logic[17] that is to perform the frame protection and verification. The alternative is to increase the logic's external memory bandwidth requirements, perhaps reducing the number of network interfaces supported.

While it is notoriously difficult to advance implementation dependent arguments in standardization efforts, IEEE 802.1AE aims at widespread deployment in LAN switching equipment. This goal can (on past experience) be met only if the incremental cost of including the security capability, and the performance impact of using it, is negligible. So it had to be possible to incorporate MACsec within a design that meets the cost/performance goals of a purchaser who, initially at least, has no interest in MAC security—avoiding any need for the equipment vendor to offer, much less design, distinct security capable variants is vital. MACsec satisfies this essential requirement. The capability has been included in a number of Ethernet interface devices and switches, irrespective of whether it is to be deployed by the end user or not, simply to avoid proliferation of variants. The performance of these implementations, both in terms of wire speed throughput and low latency (of the order of a minimum packet size[18]) has kept pace with increases in transmission speed. They

[14] NIST SP 800-38D. GCM–AES is also used in IPsec, SRTP (Secure Real-time Transport Protocol), and Fibre Channel Security Protocols (FC-SP) amongst other uses. http://en.wikipedia.org/wiki/Galois/Counter_Mode provides a useful introduction. Many detailed implementation studies are publicly available.

[15] See http://en.wikipedia.org/wiki/Advanced_Encryption_Standard and http://en.wikipedia.org/wiki/Rijndael_key_schedule for a brief description.

[16] This description may over simplify, but contrasting the 176/240 octets (for 128 and 256-bit secret keys respectively) of the round keys against the 96 octets of a minimum sized-packet (with MACsec SecTAG and ICV) makes the point. A small amount of additional key-specific (or at least SA specific which amounts to the same thing) management data is also needed.

[17] Perhaps immediately accessible through multiplexing logic, or close by on chip with wide bus access.

[18] The (small) added delay can be made quite predictable. This low jitter can be important in time sensitive networking applications. The parallelization capability of GCM means that it is entirely feasible to use a pipelined implementation to maintain full wire speed for indefinite back-to-back minimum frame size transmission/reception, though the usual 65 byte frame considerations may make this a commercial consideration.

necessarily protect or verify frames as they are being transferred in and out of memory (or between memories). Otherwise memory bandwidth would have to be greater than that required for non-MACsec capable implementations, as an inevitable consequence of encrypting or decrypting (and thus changing) frame data as well as adding or removing the SecTAG (security header) and ICV (trailer). This increase would be in addition to any due to using large numbers of secret keys[19].

The fact that MACsec processing can be incorporated in high volume and cost effective network interface components, not intruding upon the rest of an end station's or switch's design and making implementation relatively easy, also lessens the likely availability of alternate processing components[20]. This may make it more difficult to insert a MACsec shim at all permissible points in an interface stack (see 4.3) in complex systems: while it may be possible to carry instructions as to where and how to insert a header in the frame, this demands significant flexibility both within the interface implementation and the rest of the system, transferring system intelligence to the interface. Attempts to procure custom MACsec capable systems may reasonably be met by refusals or special engineering costs, even if the required interface stack arrangements meet 'the letter of the law' for use of the MACsec shim. On the other hand the functionality of complex systems, e.g. Backbone Edge Bridges (BEBs), can often be realized economically by separate connected systems, mirroring their standard specification. In all events we attempt to work toward a short catalog of useful systems and interworking arrangements.

Implementing LAN security in a way that imposes the lowest possible cost on those who are either uninterested or marginally interested also means paying attention to detailed security requirements, or sometimes the lack of them. See 3 above. In particular links directly connected to end stations may not be exposed, so the task of deploying on the most numerous devices can be avoided or postponed.

4.2 Protecting frames

Consider the network fragment shown in Figure 5 (a). End stations ES1 and ES2 are connected by VLAN bridges B1 thru B3. Each of the connecting LANs/links is shown in red, to indicate that they are exposed to attack, carrying data that ought to be protected. How should this be done?

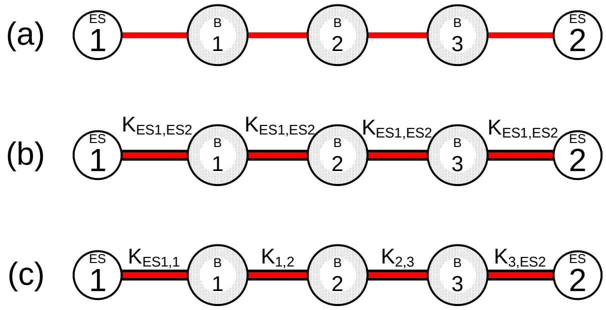


Figure 5—Protection along a path

An 'end-to-end' approach (Figure 5 (b)) protects the frame (shown in the figure by covering the links along the path with black) with a key ($K_{ES1,ES2}$) agreed between (and known only to) the two end stations. This has a few downsides:

- The bridges cannot check the frame integrity, and thus safely learn[21] (or refresh) station locations from the MAC source address (3. above), unless each of them also possesses $K_{ES1,ES2}$.
- A bridge cannot make (and protect) a change to the frame that would be permitted in (and may be essential to the operation of) an unsecured network, unless it also possesses $K_{ES1,ES2}$. For example, ES1 might transmit a frame without a VLAN tag, with B1 adding it (with the appropriate VLAN ID). Other stations, in different parts of the network, might be assigned to different VLANs, with all these frames (including their VLAN IDs) being destined for the ES2. In one typical network arrangement ES2 is a router, and the VLANs correspond to IP subnets. Two stations, on different VLANs/subnets, might have the same MAC address. The assigned VLAN IDs have to be protected if one station is to be prevented from masquerading as another.

MACsec uses the 'hop-by-hop' approach shown in Figure 5 (c). A different key is used for each hop (LAN), with each participant validating the frame using the key for the reception LAN, and reprotecting the frame for onward transmission. While receiving station has to trust not only the transmitting end station, but also the intervening bridges this is also the case for the end-to-end approach (b)—once the latter is extended to permit and protect normal bridge functions (learning, VLAN assignment,...). In both cases a secure infrastructure has to be established, and

[19] At the time of writing a few ten's of keys is a typical upper limit. This is sufficient to to support virtual ports on a shared LAN serving end stations.

[20] Though not of gate designs for inclusion in custom chips. High performance end station implementation using Intel processors has been facilitated by the new instructions specifically targetted at GCM-AES.

[21] This is a vital part of a bridge's handling of network reconfiguration or end station movement.

the users of the network provided by that infrastructure need to trust it.

The difference between these approaches is readily apparent when communication from ES1 to an additional station, ES3, is considered (Figure 6).

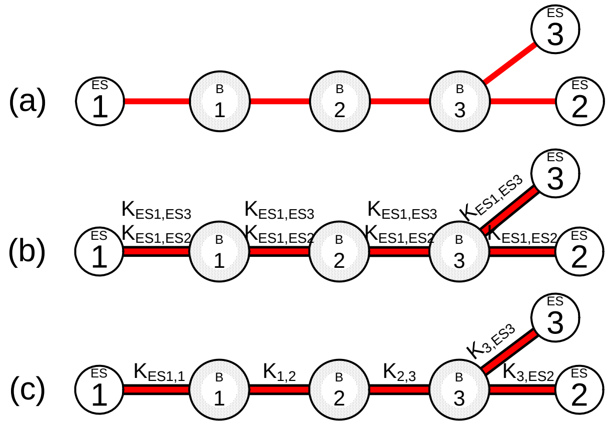


Figure 6—Protection to multiple stations

The end-to-end approach (b) requires a key for each communicating pair of stations, and each such key needs to be known by intervening learning bridges or by any bridge that needs to modify the frame[22].

The hop-by-hop approach facilitates incremental deployment. Initially it may be important to secure one link in the network (B3–B4 in Figure 7 (a)), while others are considered immune from attack even if not explicitly secured (shown as green in the figure).

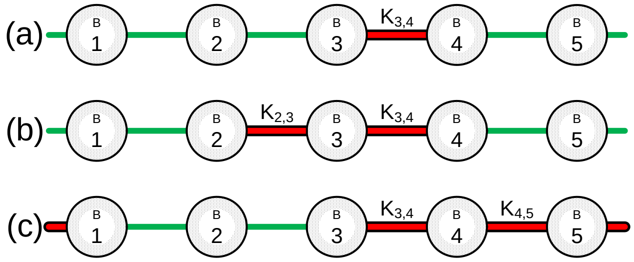


Figure 7—Protected and trusted LANs

The protected region or portion of the network path can then be extended, as in Figure 7 (b), though protected traffic within the region cannot be trusted unless appropriate controls/policies are applied to traffic entering it. If part of the network is truly immune from direct interference (the LANs connecting B1, B2, and B3 in Figure 7 (c) might be completely contained in a locked closet, for example) then they can form part of the trusted region.

The case where the physical connectivity to B2 is actually exposed to attack, and only unprotected because B2 itself lacks the capability, is more difficult. If B2 does not modify any of the frames it forwards (and those it originates are readily identifiable and subject to sufficient ingress policy controls by the adjacent bridges) it is tempting to protect the path from B1–B2–B3 with a key agreed by B1 and B3 (Figure 8 (a)). However this can pose problems. Almost all network designs provide alternate paths to protect against device or link failure (as in (Figure 8 (b)). A failure of the link B2–B3 should divert traffic from B2–B3–B4 to B2–B30–B4, and may well be supported by rapid reconfiguration protocol mechanisms (aimed at meeting or bettering a 50 millisecond service restoration time). Notifying B1 of the failure and having B1 and B3 agree and install the new key[23] is not currently part of such mechanisms and is unlikely to fit within the time budget.

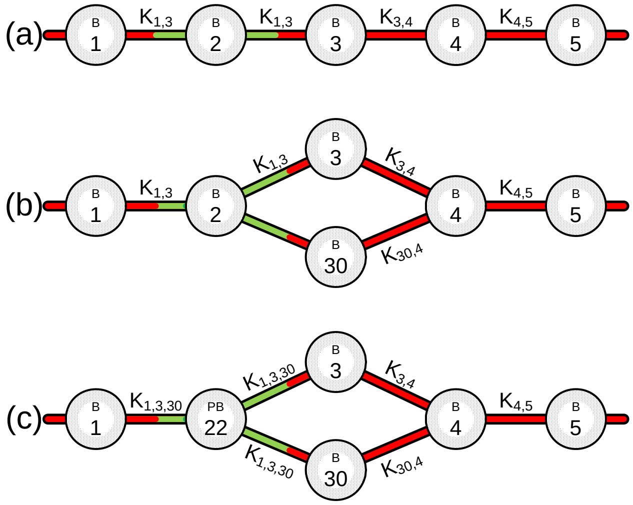


Figure 8—Network reconfiguration

However if B2 really does not modify forwarded frames it may be possible to treat it as operating at a lower (sub-)layer, as a Provider Bridge (Figure 8 (c), for example). In that case B1, B3, and PB30 are really one hop apart from the point of view of their network configuration protocols—they are all attached to the (virtual) shared medium supported by PB22—and can agree a group key.

Two systems may not be immediate neighbours for an instance of a configuration protocol in which they both participate, but the path protected by that configuration protocol may be constrained to pass between the two systems—if it passes through either

[22] Addition of a tag is not the only potential modification. The priority bits in the tag can also be changed as part of normal class of service handling. After such a modification the frame would need to be reprotected with a key acceptable to the recipient.

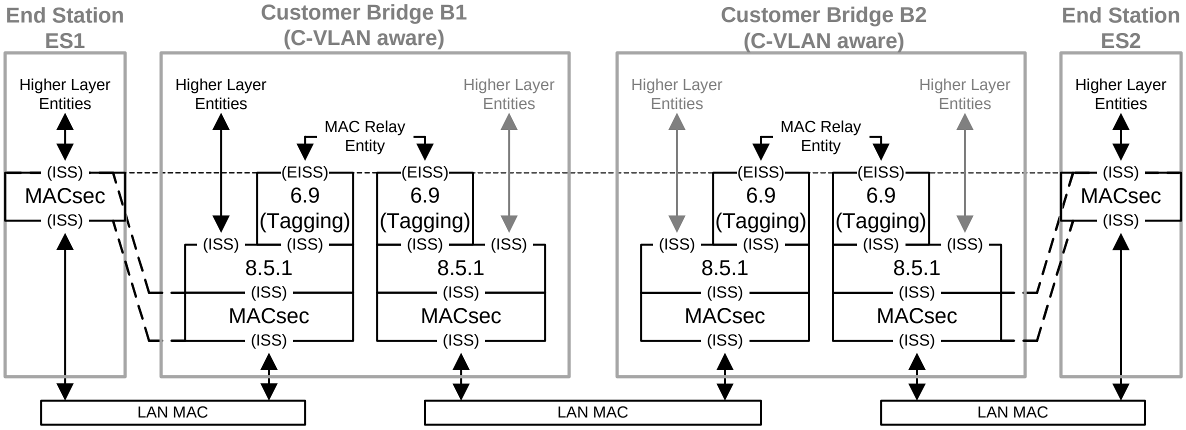
[23] In some cases the path B2–B30–B4 would not exist prior to the failover while the required key cannot be agreed until it exists, in other cases the path only exists for the purposes of supervisory traffic, which would not naturally report to B1, and in any case does not support key agreement protocol.

of them. In that case it may be possible to omit the intervening systems from the configuration protocol, effectively placing them at a lower (sub-)layer, as in the above, and making the systems immediate neighbours. Simply forwarding Nearest Customer Bridge group addressed frames (see Table 1) through the C-VLAN components of Provider Edge Bridges has that effect.

4.3 The MACsec shim

The paradigm of connectionless networking, in which communicating peers can exchange data without previously participating in an explicit exchange to setup a connection (as required by X.25 or TCP), is now so prevalent as to pass without comment[24]. The notion of a 'connectivity association' as an a priori association between communicating peers—that is to say an association that is assumed to exist and that has been created without their explicit knowledge[25]—remains useful. What concerns us is the connectivity association between neighbouring peers at a given (sub-)layer—the simple ability of a set of protocol entities to exchange frames without the need for the frame to be relayed at that (sub-)layer. This is the 'single hop' that we wish to secure, and in general we wish to secure it without the explicit involvement of the communicating peer protocols—otherwise we would fail in our goal (see 3 above) to keep pace with the new protocol development that continues largely independently of security concerns.

This secure connectivity association (CA, as defined by 802.1AE) formalizes our notion of a secured instance of the ISS, defining its extent and participants. The connectivity association implied by the existence of the ISS at any point in a protocol interface stack can be secured by the insertion of protocol entities whose operation is transparent to that of the existing protocol entities above and below. Such transparent protocol entities are known as 'shims'. Figure 9 (compare to Figure 2) provides an example.



NOTE—This figure has been simplified to show the addition of MACsec functionality as a single shim, comprising both the MAC Security Entity(SecY) that carries out the frame protection and validation operations, and the associated PAE and KaY (see 802.1X-2010) that facilitate authentication and key agreement. The latter make use of an Uncontrolled Port provided by the SecY. This figure and similar figures in this note show only each SecY's Common Port (below MACsec) and its Controlled Port (above MACsec) and allows communication between peer PAEs and KaYs to be shown as communication between peer MACsec entities.

Figure 9—Securing the ISS in VLAN-aware bridges and end stations

Three connectivity associations (ES1–B1, B1–B2, B1–ES2) have been secured by the addition of the MAC Security Entities (SecYs). In addition to cryptographically protecting frames that pass between its upper (Controlled, or secured) port and its lower (Common Port), each SecY also supports transmission and reception of unprotected frames (through an Uncontrolled Port) so that companion protocol entities (PAEs and KaYs) specified in 802.1X-2010 can authenticate, reauthenticate, and agree keys with the other participants or potential participants in the CA[26].

[24] See RFC 787 for a useful tutorial.

[25] The term 'a priori' does not simply mean 'prior', nor is it restricted to discussions of probability. See the Wikipedia discussion of 'a priori' (knowledge independent of experience) and 'a posteriori', and A.C.Grayling's 'An Introduction to Philosophical Logic' (Chapter 3). In the present case examples of events and actions outside the media and subnetwork independent experience of protocol entities include plugging an Ethernet cable into a network, and setting up an ATM connection that will subsequently carry UDP packets. All that the protocol entities know is that they can, once active, transmit packets.

[26] Clearly no participant is to be given a key to participate in secure communication until mutual authentication has taken place. Authentication thus either implies, or is followed by, authorization. Authorization may result in changes to the management variables of other protocol entities—permitting or denying access to certain VLANs, for example.

4.4 CA Scope

The scope of a CA (if connectivity is permitted at all) is thus determined by the scope of the addresses used for authentication and key agreement. Management controls for the SecY determine whether insecure connectivity is permitted, or indeed whether the connectivity is to be secured at all. Moreover received frames are (at least notionally) passed both to the Controlled Port (for possible relay, if the system is a bridge) and the Uncontrolled Port (for use by authentication and key agreement). The destination address of the frame determines whether the relay's FDB will allow forwarding, and whether the PAE or KaY (Key Agreement Entity, see 802.1X–2010) will wish to process the frame.

Consider the connectivity between Customer Bridges B1 and B2 in Figure 9. The MACsec PAE and KaY for B1's right-hand port, and those for B2's left-hand port, can be configured to transmit and receive using either the Bridge Group Address (also known as the Nearest Customer Bridge group address) or the PAE group address (also known as the Nearest non-TPMR Bridge group address). Either will work in this scenario: both are filtered by the MAC Relay Entities of B1 and B2, restricting EAPOL (EAP over LANs) and MKA (MACsec Key Agreement) exchanges to the two ports.

Replacing the LAN connecting the two ports with a provider bridged network service[27] introduces a further possibility. The intent may be to secure connectivity across the PBN, between B1 and B2, as in Figure 10. In this case each PAE and KaY should use the Bridge Group Address for EAPOL exchanges (if required) and to agree keys (using MKA). Frames with this address will be forwarded by the MAC Relay Entities of the intervening Provider Bridges.

Alternatively the intent may be to secure connectivity to the provider bridged network, from both or either of B1 and B2. See Figure 11. In this case the Nearest non-TPMR Bridge group address should be used, and EAPOL and EAP exchanges occur between each Customer Bridge and the Provider Bridge that supports its interface to the PBN.

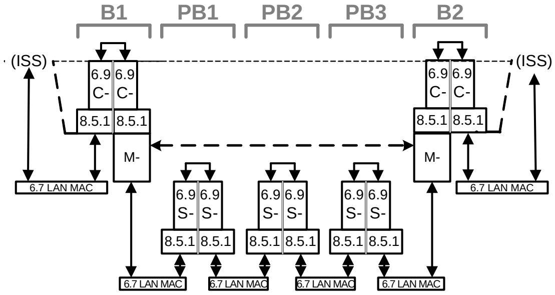


Figure 10—MACsec across a PBN

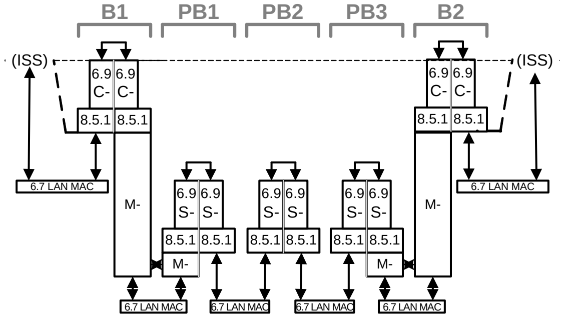


Figure 11—MACsec to a PBN

As a further alternative, the MACsec shim (and its associated control protocol components) may appear twice[28] in the Customer Bridge Port's interface stack: securing communication to the provider's network and (separately) securing communication across it as described in 802.1AE 11.7 and Figure 11-13.

4.5 MACsec end-to-end

It is possible (in theory at least) to operate MACsec end–to–end, and this possibility is not infrequently suggested by those new to MACsec. This note is largely about the reasons why this is rarely a good idea. It does make sense when the 'end–to–end'[29] connectivity can be considered equally to be a single hop, as described above. Very briefly: the traffic to be protected flows between the two ends or not at all (specifically there is no reason for sending it from either end if it is not to arrive at the other), and is not destined for (nor has any effect upon) any other system on any potential path from one to another. These criteria are met by customer traffic when PBN point-to-point services[30] or PBBN services are used—the traffic is segregated by S- or B-VLAN.

[27] Port-based service interfaces are shown to simplify the diagram and discussion.

[28] I do not know if this configuration is commonly supported by single systems (the considerations outlined towards the end of 4.1 would suggest otherwise) but access to the PBN could easily be provided by a separate MACsec capable NID (Network Interface Device). If the NID design follows 802.1 standards it is likely to be a TPMR, in which case EAPOL and MKA might well use the Individual LAN Scope group address (see 802.1Q-2012 Table 8-1).

[29] The ends of the 'end-to-end' connectivity may refer to ultimate source and destination of the communication, probably coincident with the ends as viewed from IP. Contrariwise in telco-speak the 'ends' simply refer to the points beyond which an organization responsible for carrying traffic no longer has financial or legal responsibility.

[30] PBN point-to-point services do not have to learn from frame's source addresses. The criteria are also met for all PBN services when all the frames accepted by the provider have been protected over the access link, denying an attacker the opportunity of spoofing MAC source addresses. PBBNs provide address independence via encapsulation. Traffic engineered services may provide other opportunities for connectivity to be declared 'effectively single hop'.

Thus the reconfiguration protocol concerns raised in 4.2 above are handled by ensuring that the ends are not affected, and MACsec (or at least that instance of it operated by the ends) does not have to play its primary role of protecting the network infrastucture between the ends (at best that is now achieved by the usual careful configuration of provider services and the possible use of further layered instances of MACsec within the provider network, see 4.4, at worst that has simply been declared an SEP (someone else's problem).

Of course this end–to–end approach may still result in one or both of the end systems having to handle a very large number of secured end–to–end connections, each with its own secret keys. Whether that is feasible depends on the relative effort of supporting those connections and of the rest of the system's workload.

4.6 MACsec end station–to–end station

The end systems for end–to–end connectivity could, so far as the MACsec protocol itself is concerned, be the MAC destination and source of the frame. This satisfies the reconfiguration protocol concern (the frame is constrained to arrive at the destination, or not to arrive at all). However it leaves open the question of what (unprotected) protocols are to be used so that the ends can discover each other and decide to set up the secured connection. Broadcast and multi-cast frames would have to be protected separately, if protected at all, so some further higher layer by higher layer protocol threat analysis would be required. Additional destination address and protocol type specific mechanisms and controls would need to be specified to assign frames to the Uncontrolled or Controlled Ports and to Secure Channels (SCs)[31].

MKA could easily use individual rather than group destination addresses (once the addresses have been discovered) but the use of EAP and EAPOL seems unlikely, if for no other reason than that the scaling mechanisms developed to support EAP Authenticators are no longer a natural fit. Use of a Kerberos/IKE based alternative would maximise the benefit of past experience, and indeed if only IP traffic is to be protected it should be possible to borrow the design wholesale from the control protocols used to support IPsec. The question is, of course, what would be the point? Such a web of point-to-point MACsec connections would not protect the MAC layer switching infrastructure itself (without an additional hop-by-hop MACsec sublayer, as mentionned as a possibility for PBNs above, in the last paragraph of 4.4) and is unlikely to perform significantly better than IPsec. Each of the end-points of each MACsec protected part of a complete IP end–to–end path would necessarily be an IP router or IP end station, removing the flexibility to use intermediate devices for protection and to protect just exposed links—the two capabilities that really make MACsec attractive.

There is a further potential issue with attempting to use MACsec end station–to–end station at present. Unless there is some intervening tagging (C-VLAN, S-VLAN, or PBBN address encapsulation) or a further hop–by–hop sublayer of MACsec is being used, then any SecYs in the intervening bridge port interface stacks will discard the protected frames (or at best remove their SecTAGs and ICVs) as their SAs will not be recognized. This is not an issue for C-Tagged or S-Tagged service interfaces (see 5.1, 5.3, and 5.4 below) but may affect the use of port-based service interfaces. For further detail see B.1 below.

5. Additional use cases

Clause 11 of 802.1AE–2006 specifies how MAC Security is incorporated within the architecture of end stations, within systems that incorporate link aggregation or the Link Layer Discovery Protocol (LLDP), within VLAN-unaware and VLAN-aware Bridges, and within Provider Bridges. It shows how to secure connectivity between Customer Bridges attached to PBNs (independently of PBN operation) and how to secure connectivity from a Customer Bridge to the first Provider Bridge in such a network, but only for port-based interfaces to the PBN. It also shows how provide independently secured access for multiple end stations connected to the same LAN. Clause 7 of 802.1X–2010 provides additional detail.

It might not be apparent, to those not familiar with 802.1Q's specification of provider bridged networks, how 802.1AE 11.7 applies to tagged as well as port-based service interfaces, so this section provides additional detail (5.1), before considering the following additional cases:

—PBBN port-based service interfaces(5.2)

—PBBN S-tagged service interfaces(5.3)

—PBBN I-tagged service interfaces(5.4)

[31] So the (significant) parts of 802.1AE that deal with MAC Security Entity (SecY) operation and its management are not directly applicable.

5.1 Tagged PBN service interfaces

The following have to be taken into account when designing the secure connectivity solution:

a) The C-VID[32] is naturally behind the SecTAG[33], and thus may be encrypted and in any case will not be accessed by an ordinary Provider Bridge[34].

b) Any given provider service instance/connection across a PBN is not constrained to use the same type of service interface at both/all interfaces. An organization's central office may, for example, use a tagged interface to distinguish between connections to a number of branch offices. The branch offices might use a port-based interface, and in any case the interface equipment has no need to understand the central office's tagged interface numbering scheme.

A natural approach to these problems is for security concious customers to use an S-tagged provider service interface and supply their own provider edge bridge functionality, either in a separate or a combined system, as in Figure 12 (compare to Figure 3). The S-TAG components (S-VID, PCP, DEI) can then be policed, modified, translated, or removed as required by the service provider, while the integrity of the customer's C-VID is guaranteed on delivery.

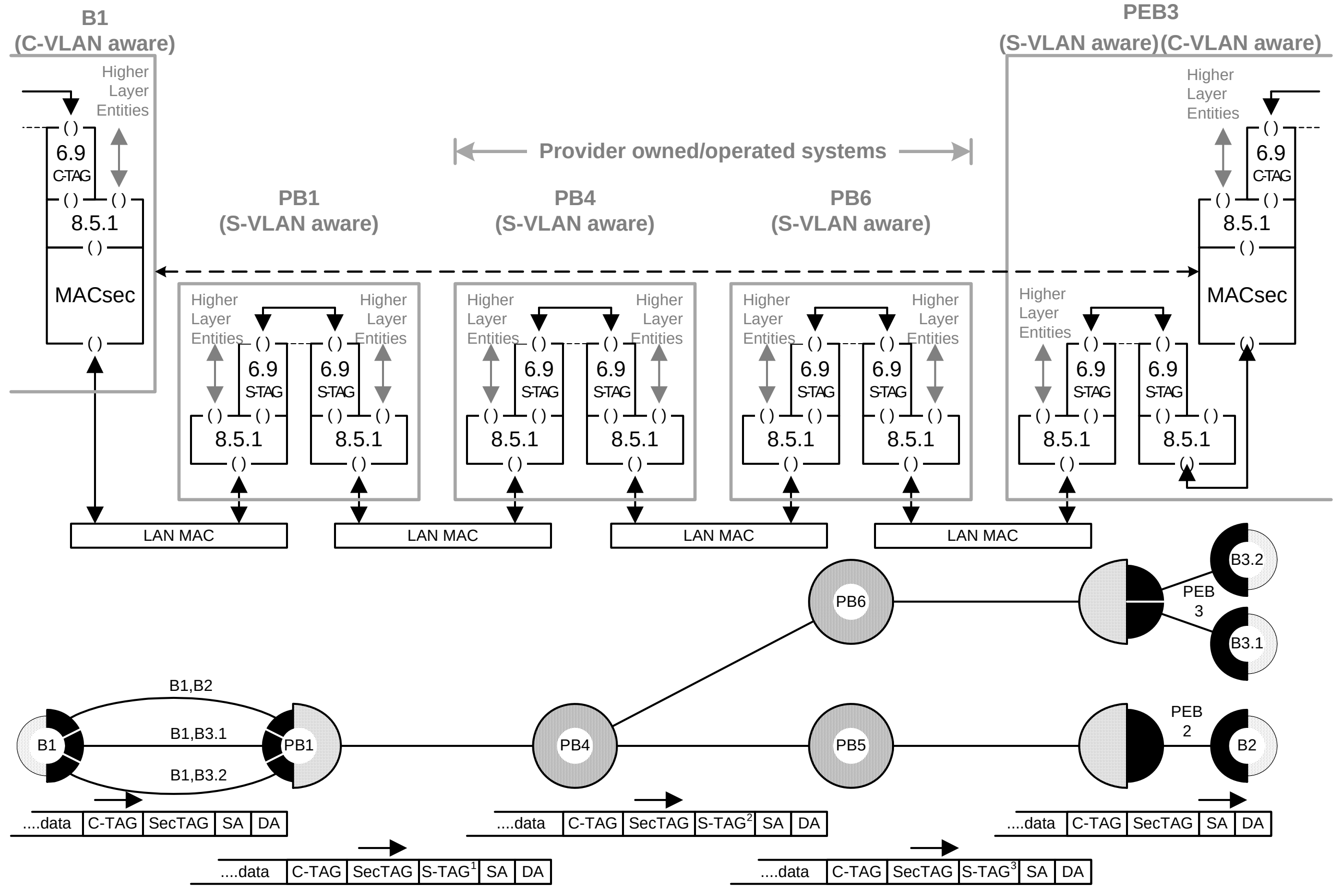

B1
(C-VLAN aware)
Higher Layer Entities
6.9 C-TAG
8.5.1
MACsec
Provider owned/operated systems
PB1
(S-VLAN aware)
PB4
(S-VLAN aware)
PB6
(S-VLAN aware)
PEB3
(S-VLAN aware)(C-VLAN aware)
Higher Layer Entities
6.9 S-TAG
8.5.1
( )
LAN MAC
LAN MAC
LAN MAC
LAN MAC
B1
PB1
PB4
PB5
PB6
PEB 3
B3.1
B3.2
PEB 2
B2
B1,B2
B1,B3.1
B1,B3.2
....data | C-TAG | SecTAG | SA | DA
....data | C-TAG | SecTAG | S-TAG1 | SA | DA
....data | C-TAG | SecTAG | S-TAG2 | SA | DA
....data | C-TAG | SecTAG | S-TAG3 | SA | DA
....data | C-TAG | SecTAG | SA | DA

Figure 12—Interface stacks and paths for PBN tagged service interfaces

Some explanation of Figure 12, covering the basic operation of a PBN and its interfaces as well as the use of MACsec, may help: A plan view of part of the network, showing three service instances connecting customer owned and operated bridges and Provider Bridges, is shown below an interface stack diagram. The latter necessarily follows the path taken by just one service instance—between B1 and PEB2—though (in this case) only the identities, rather than the interface stacks, of some components would differ if another service instance were to be depicted. On the left the MACsec processing and the addition of the S-VID that identifies is shown split over two systems (B1 and PB1), while on the right a single PEB3

[32] The Customer's (C-VLAN's) VLAN Identifier.

[33] The MACsec header.

[34] Either MACsec unaware or with a MACsec interface stack as specified by 802.1AE–2006.

provides both C and S component functionality[35]. The header format for each frame transmitted, from B1 on any of the service instances, is also shown.

Frames for several different Customer VLANs (C-VLANs) can be carried on any one of the provider connections (since each of these is providing a point-to-point service there is no need to learn from the source addresses of customer frames within the provider network, and hence no need to speculate as to whether the customer's MAC addresses are unique amongst C-VLANs carried by a single service connection). Following a frame from left-to-right, it is:

—Forwarded by B1
to just one of the right-facing ports of B1, as the FDB is configured to permit egress for the frame's C-VLAN only on that port and one or more of the left-facing ports of B1 (not shown).

If that C-VLAN is the only one to be carried on the connection and the C-TAG is not required to carry the frame's priority it could be removed and the frame passed down the stack and across the connection untagged.

—Transmitted through one of B1's ports[36]
protected by, and with the SecTAG provided by, the MACsec shim for that port onto one of the three LANs connecting B1 to PB1.

—Received by PB1 and assigned to an S-VLAN
using the receiving port's PVID[37]. Thus B1's egress port decision has identified the connection for the frame on the basis of the latter's C-VLAN.

—Forwarded by PB1 to the PBN, and through the PBN on the basis of the S-VLAN to PEB 3.

The S-VID value is policed and typically translated by PB4 on ingress to the PBN, allowing the provider to organize or reorganize the S-VIDs used within the network without impacting any customer.

—Forwarded by the S-VLAN component of PEB3
(on the basis of the S-VLAN) to one of its ports, which removes the S-TAG, and transmits the frame

The port concerned lies within the PEB and can be realised by any technology that meets the requirements of 802.1Q 6.14 (Support of the ISS within a system).

—to a port on C-VLAN component B3.2, whose MACsec shim validates the frame and removes the SecTAG.

—Forwarded by B3.2 to its other port(s) on the basis of its C-VLAN and destination MAC Address.

The PAE and KaY[38] associated with the MACsec shims of B1's and B3.2's ports communicate over the same S-VLAN tagged path, using the Nearest Customer Bridge group address which is not filtered by any of the intervening S-VLAN components (see Table 1), as the destination address of each frame.

The interface stack and path just described do not provide a way for B1 to communicate the ISS's priority parameter information to PB1 on a frame by frame basis unless that capability is an inherent part of LAN MAC—Ethernet lacks this. IEEE 802.1Q 6.13 (Support of the ISS for attachment to a Provider Bridged Network) remedies this deficiency by allowing the C-VLAN bridge component to priority tag each frame with an S-TAG[39]. Figure 13 shows the interface stack for each of the C-VLAN bridge components of Figure 12 with the addition of this capability. There is no need for the S-VLAN components of PB1, PEB2, or PEB3 to communicate this information to the C-VLAN components, as the latter will recover the original C-TAG's priority field from the frame after MACsec validation.

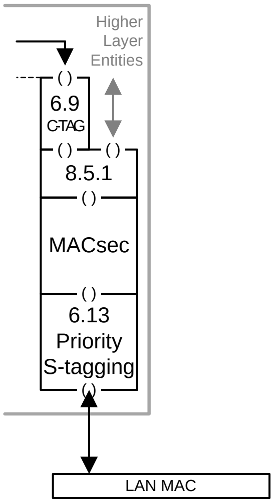


Figure 13—Communicating priority from a secured C-VLAN component

[35] This difference has been introduced merely to indicate this possibility, the relative positions of B1+PB1 and PEB2 could equally well be reversed, or both ends of any provider service instance/connection over the same network could be supported by separate (or combined) systems.

[36] In general 'port' refers to the interface stack associated with an ISS interface, though it is often convenient to emphasize the associated processing by using the term 'interface stack' and to emphasize the physical connectivity by using the term 'port'. See 802.1X-2010 D.4 or 802.1Q–2011 6.1.4

[37] Port-based VLAN Identifier (the rceiving port treats the frame as untagged).

[38] The PAE (Port Access Entity) and KaY the Key Agreement Entity, part of the PAE, see 802.1X-2010)

[39] Priority tagged frames convey have 0 in the VID field. Note that the intrerface provided by the 6.13 shim is the ISS, not the EISS and

5.2 PBBN port-based service interfaces

These interfaces are described in 802.1Q 25.3 "The PBBN Port-based interface provides the same type of service as the PBN Port-based interface..." and illustrated in 802.1Q Figure 25-4. All S-tagged frames presented to the interface are required to have a null VID, i.e. from an S-VLAN components point of view they are untagged or priority tagged. A suitable interface stack for the attached customer equipment is that shown for B1 in Figure 12, or that shown in Figure 13 if priority selection is occur on a frame-by-frame basis. The frame is forwarded over the backbone without an S-TAG, though this is of little concern to the customer who delivers and receives his MACsec protected frame to and from the service just as specified for a PBN (see 5.1 above).

The backbone adds I-TAGs (conveying an ISID, or service identifier) and B-TAGs (adding encapsulating addresses) but these are outside the scope of the customer's MACsec protection and are removed before the frame is delivered to the receiving customer equipment.

The Nearest Customer Bridge group address used by the PAE and KaY is encapsulated over the backbone, so authentication and key agreement proceed just as before.

5.3 PBBN S-tagged service interfaces

Again this interface (described in 802.1Q 25.4) behaves, from the customers point of view, in the same way as an S-tagged PBN service interface, and the interface scenario follows that for 5.1 above.

PBBNs do not offer a C-tagged service interface, so present none of the minor complications that arose in considering this interface for PBNs (5.1).

5.4 PBBN I-tagged service interfaces

A customer of a PBBN I-tagged service interface (802.1Q 25.5) is most likely to be the operator of a peer attached PBBN uses a Backbone Edge Bridge to connect. The ISID supplied by the customer is mapped 1-1 to an ISID within the PBBN, and is not otherwise carried through the PBBN. Since the intent is that the ISID supplied across the interface be changed, or at least open to change by the PBBN, there is no sense in which it is desirable to ensure its integrity when delivered at the distant end of the connection throough the PBBN. A common reason for interconnection of PPBNs in this way is to allow two operators to extend their joint area of service availability and it is most likely that the PBBN will deliver the frame not to the I-tagged service interface user but to some common customer who has no interest in the particular ISID value, but may simply want to confirm (by MACsec operating above the level of the PBBN, and not protecting the I-TAG or B-TAG) that he has received a (possibly encrypted) frame that his authenticated peer originally transmitted.

Protection of communication directly between the BEB attached to the service interface and the PBBN itself is a different issue, and can simply be achive over this very simple hop by using MACsec at the lowest layer in the interface stack as can be done for PBN interfacing (see 802.1AE-2006 Figure 11-13).

6. Follow-up

This note has pointed out some deficiencies of current standards, or at least areas that could be expanded or improved to their users' benefit. Ideas on what might be done follow.

6.1 BEB S-VLAN component addresses

The S-VLAN components of Backbone Edge Bridges (BEBs) have the same reserved addresses as those of Provider Bridges (see 2.3 final paragraph).

A. FAQs

B. Additional technical detail

B.1 Transparent SecY operation

802.1AE's specification of received frame processing and management controls currently do not allow a SecY to configured as totally transparent: i.e. to operate as if it were not present in the interface stack.

<<Why this was a deliberate choice, wisdom or otherwise of making this choice flexible, limits of plug-and-play vs limits of safety in configuration.>>