Discussion of Ethernet Link Security for Inter-Datacenter Interconnection

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Topics

- Overview
- Requirements
- Gap Analysis
- Proposal

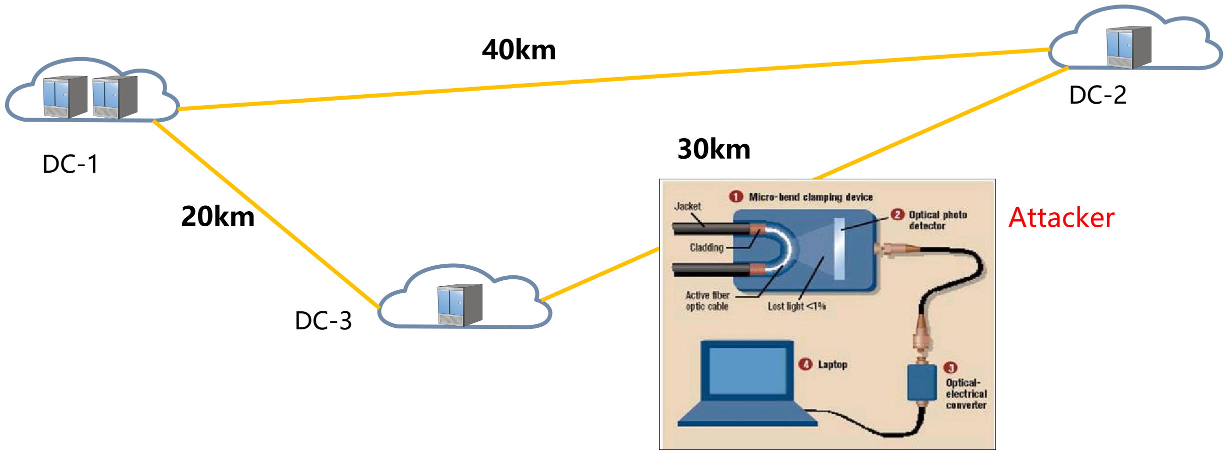
Overview

- This topic has been presented in Nendica to gather more interest and feedback.
  - In 2024, the presentations (802.1-24-0036, 802.1-24-0053, 802.1-24-0056) focused on a Direct-Detection physical layer security solution for intra-datacenter, which utilized AES-CTR.
  - From 2025, the proposals (802.1-25-0010, 802.1-25-0014) introduces a coherent physical layer security solution for inter-datacenter, which employs the AES-GCM.
  - Currently, we would like to first discuss the solution for inter-datacenter scenario.
- T**his topic involve both knowledge of Ethernet physical layer and security**. It has been recommended that the presentation could be delivered within the 802.1 Security TG, with participation from 802.3 experts invited for discussion.
- This contribution intends to:
  - **Discussing the security requirements of inter-datacenter links.**
  - introducing the overall framework of potential physical-layer solution including **Data Plane of Confidentiality, Integrity and Data Origin Authentication, and Control Plane of Authentication, key agreement, port control, and etc**.
  - We aim to explore this topic and its feasibility for standardization within the 802.1 Security TG.

Security Requirements on inter-Datacenter Links

- **Massive data over DCI links is valuble and privacy-sensitive.** Datacenters are a critical infrastructure for cloud computing and AI/ML application, storaging and processing mass sensitive data[1,2]. These valuable data also need to be transimitted bewteen DCs in some application senarios, and become potential eavesdropping targets over DCI links.

- **DCI links is vulnerable in secruity.** Eavesdroppers can intercept optical signals and acquire sensitive data by bending optical fibers, posing a threat to the security and privacy of DCI links exposed to the open physical environment[3].



- **Encryption of DCI links should be mandatory.** The possible methods used to encrypt data of DCI links include MACsec, etc.

[1]. Security risk assessment within hybrid data centers: A case study of delay sensitive applications
[2]. Data Center Secure Communication via DNA Hyperchaotic Encryption
[3]. Eavesdropping G.652 vs. G.657 fibres: a performance comparison

Gap Analysis of Prior Mechanisms

① **MACsec will expand the Ethernet frames due to the addition of Security Tag + ICV (32 Bytes).**

- The addition in the frame will expend extra bandwidth. Taking the 64-byte frame as an example, the ratio of bandwidth overhead will exceed 30% (=32/(32+64)).
- Considering the uncertainty of frame lengths in actual networks, bandwidth resources for security are typically provisioned for the worst-case scenario (64bytes). Thus, over 30% additional bandwidth need be allocated in advance.

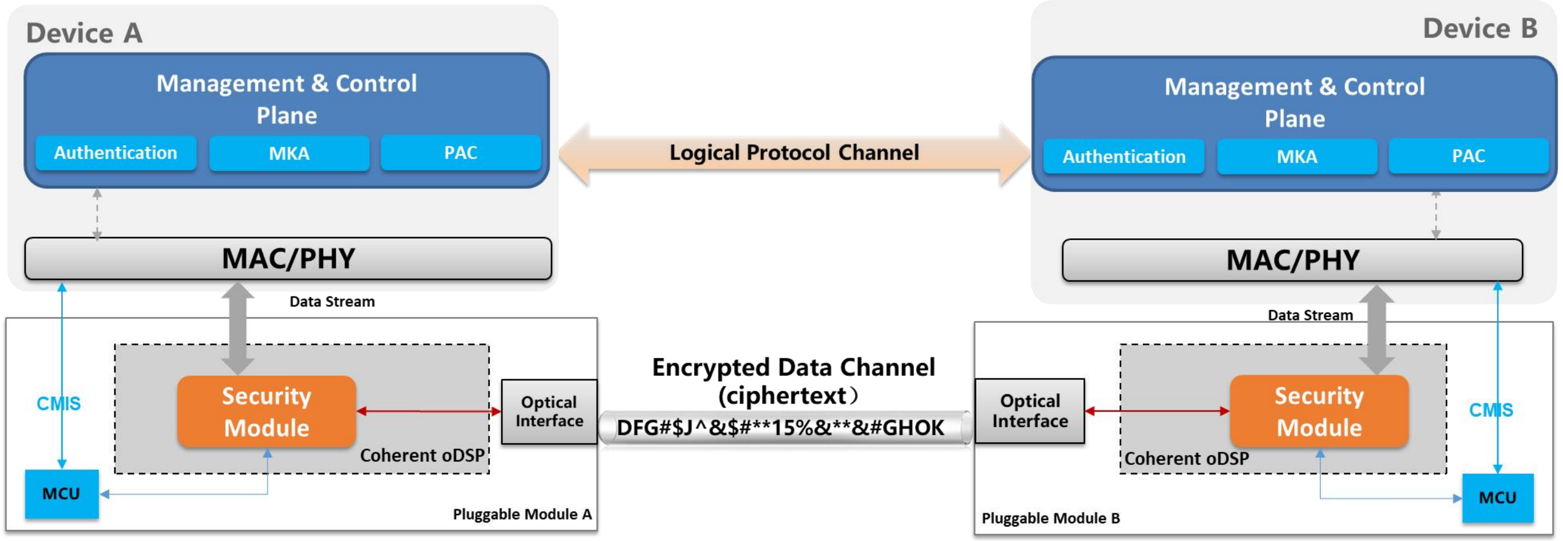
② **MACsec can not protect Pause or Priority Flow Control (PFC) frames,** and maybe potentially used to attack data processing within the data center. Although 802.1Qdt is formulating protection measures for PFC, the MAC layer will introduce more complex to do this.

③ **Deploying MACSec on pluggable optical modules poses challenges.**
The requirement to implement encryption within pluggable optical modules has emerged with the advantage of easy deployment. This generally requires the implementation of the entire PHY stack back-to-back within oDSP for MACsec.

④ **MACSec can not provide full encryption.**
Unable to provide encryption for Ethernet control frames (e.g., PFC, LLDP, BPDU, …) and Ethernet packet characteristics.

Proposal for Ethernet Physical Layer Security

- Design concept:
  - ✓ **Data plane:** Using the same methods from FlexOsec in ITU-T G.709.1, as suggested by Maniloff Eric, a matter expert in 802.3 coherent PHY
  - ✓ **Management and control plane**: Authentication with EAP, MKA, Port Control, etc, referred to 802.1X
- This design bridges the aforementioned gaps by implementing cryptography at the physical layer with full encryption, while leveraging reserved PAD fields to carry the cryptographic parameters without incurring additional bandwidth overhead. Implementing encryption within pluggable optical modules brings the advantage of easy deployment.



Ethernet Physical Layer Security Supports the Security Objectives of MACsec

Security Objectives	MACsec	Ethernet Physical Layer Security
Data Integrity	GMAC generates authentication tag in **Ethernet frame header** to verify data tampering and identity impersonation	GMAC generates authentication tag in **tributary frame pad** to verify data tampering and identity impersonation
Data Origin Authenticity		
Data Confidentiality	AES-GCM encryption of **Ethernet frame payload**, resistant to brute force attacks	AES-GCM encryption of **tributary frame payload**
Replay Protection	Packet Number in **Ethernet frame header** + Replay Window	Packet Number in **tributary frame pad** + Replay Window
Time Bounding Delivery	Series mechanisms (The MAC Services, Replay Protection, and SecY transmit & receive delay) ensure the **maximum frame lifetime** (2 seconds).	**Maximally inherent from MACsec**

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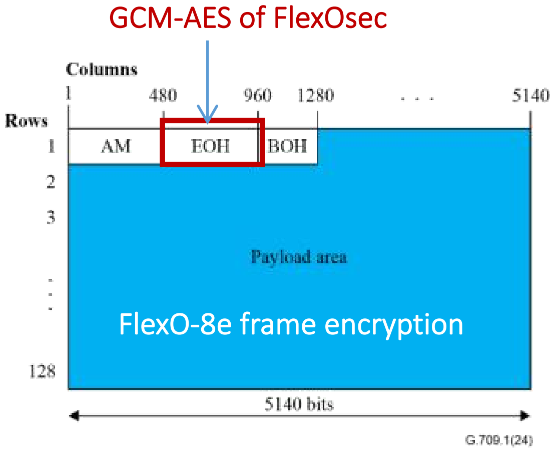
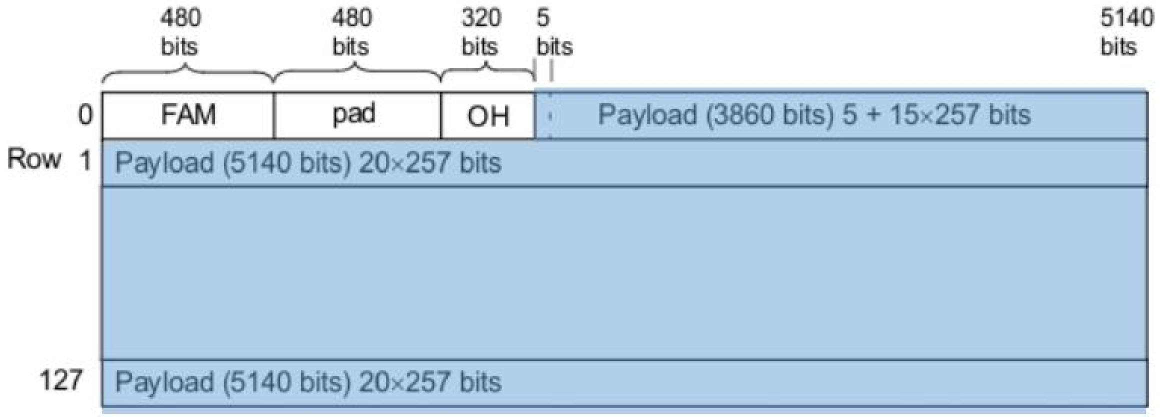
Data Plane: Using the Methods Similar to FlexOsec

- 800GE ER1-20 and ER1 objectives currently standardized by IEEE P802.3dj are just suitable for DCI. Such objectives referred to and reused the physical-layer technologies specified by ITU-T FlexO (G.709.1). Specifically, considering physical layer security (see following figure):
  1. FAM is used for delimiting tributary frames. During the process of physical layer encryption with AES-GCM, FAM+pad are not encrypted;
  2. In the current 802.3 dj (Draft 2.0) specification, the pad field is all zeros, and the receiving side ignores this field. The physical layer security uses part of the pad field to carry cryptographic parameters (e.g., ICV, KI, etc). This mechanism allows for **zero-overhead transmission of security parameters;**
  3. The upper-layer frames & packets (data or protocol) are carried by the payload of the tributary frame, so **all information at the upper layer will be encrypted**, including inter-frame gap, frame headers, and other details.




480 bits
480 bits
320 bits
5 bits
5140 bits
Row
0
1
127
FAM
pad
OH
Payload (3860 bits) 5 + 15×257 bits
Payload (5140 bits) 20×257 bits
Payload (5140 bits) 20×257 bits

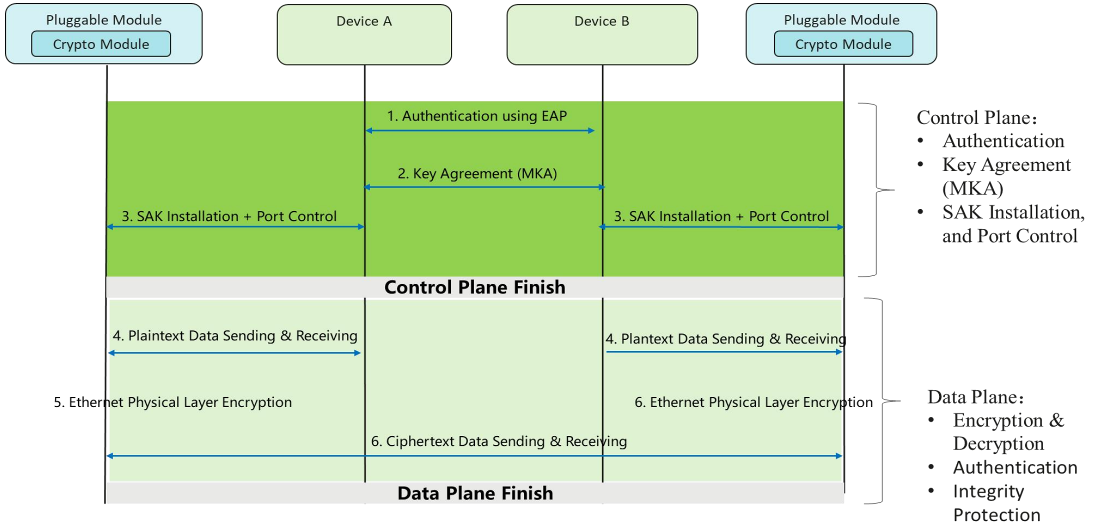
Management and Control Plane: Directly Inherits from 802.1X-2020

- **The complete operational process:**

The device uses EAP to complete identity authentication -> The device uses the MKA protocol to complete key agreement -> SA & SAK installation into optical module -> opening of the MACSec controlled port, enable physical security in optical module -> Data transmission with physical security.

- **Specifically, regarding the controlled and uncontrolled ports:**
  1. During session setup, control protocols authenticate via the uncontrolled port. If successful, keys are delivered to the optical module and the controlled port opens. If it fails, the port stays closed and the module's security is disabled.
  2. After initial setup, re-authentication messages pass through the optical module's security layer, which already has synchronized keys for encryption. MAC layer protocols proceed unaware of this physical layer processing.
  3. If encryption/decryption keys become misaligned, continuous CRC errors occur due to broken mapping of plaintext message content and its CRC. This triggers a link failure, which forces both sides to restart the secure session establishment from the beginning.

Reusing MACSec's proven key management mechanism avoids reinventing the wheel for physical layer security.



Pluggable Module
Crypto Module
Device A
Device B
Pluggable Module
Crypto Module
1. Authentication using EAP
2. Key Agreement (MKA)
3. SAK Installation + Port Control
3. SAK Installation + Port Control
Control Plane Finish
4. Plaintext Data Sending & Receiving
4. Plantext Data Sending & Receiving
5. Ethernet Physical Layer Encryption
6. Ethernet Physical Layer Encryption
6. Ciphertext Data Sending & Receiving
Data Plane Finish
Control Plane：
• Authentication
• Key Agreement (MKA)
• SAK Installation, and Port Control
Data Plane：
• Encryption & Decryption
• Authentication
• Integrity Protection

The CMIS interface mechanism between the device and the optical module is out of scope.

Summary of Progress on Pending Issues

	Comments or Questions	Quick Answer
Cryptography Related	How control & management plane run and the relation with data plane	Directly Inherent 802.1X-2020
	The relationship and mutual influence between FEC and encryption engines	The coherent optical module first performs FEC and then executes cryptographic processing
	Attack model must be considered comprehensively in Ethernet physical layer	See page 7
	How to Adapt the MACSec Port Control Mechanism, and the influence to YANG model	See page 9
Performance Related	The latency introduced by integrity checks at PHY-layer	for coherent PHY, the transmission delay over the fiber link alone exceeds 100μs. The delay required for ICV operations is negligible
	Visualization of Security Association Parameters for the 802.3 Physical Layer	See page 8
	Message header overhead benefits, and comparison with overhead introduced by 802.1AEdk	See page 5 and 8

Q&A!