Comparative Analysis of Link Security Mechanisms

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Link security: Comparative Analysis

- **Need and Scope of Link Security**

- **Comparison of current models**
  - IEEE 802.11 Security
  - IEEE 802.15 Security
  - IEEE 802.16/DOCSIS
  - FSAN

- **Summary**
  - Threats & Countermeasures.

Link Security

- **Imposing end-to-end security to accommodate a shared link in the path is not an option**
  - What protocol should be used? IPsec? IEEE 802.10?
  - How can we mandate the use of security to all end equipment in the world?
- **Link security has been added to all subscriber access technologies with shared topologies:**
  - 802.11i
  - 802.15
  - 802.16/DOCSIS (BPI+)
  - FSAN G983.1 (ITU-T Q.2 SG15)
- **Is there a middle ground?**

Link Security Needs

- **Upper layer security cannot protect**
  - its meta-data: layer headers
  - Lower layer meta-data: headers, control, management data.
- **Different links in the path of end-end communication**
  - May have specific threat characteristics unaddressed by upper layer.
    - may begin and end before end-end communication completes
  - Different layers of routing at hops can change threat model
    - IP routing vs. LAN bridging
- **Downsides**
  - Bulk protection of data at lower layers carries more burden (power, cost)
  - Adds to overheads if higher layer security is present
  - Authentication still require higher layers: harder reach at lower layers

IEEE 802.11 Security

- **802.11 most widely deployed Wireless LAN standard**
- **Most common topology: Hub–Spoke (AP-station) model**
  - Hubs (AP) may connect to wired network (infrastructure) (BSS)
  - Broadcast medium that any outsider WLAN station/AP can listen on & transmit to.
- **AdHoc networks (peer-peer) of stations allowed (IBSS)**
- **Current WEP security flawed, new draft standard in the works, 802.11i – a.k.a RSN (Robust Security Network)**
  - RSN is a common framework that addresses the AdHoc and Infrastructure modes.
  - RSN = 802.1X + CCMP

802.11 Threats

- **Spoofing**
  - An AP or station identity may be impersonated.
- **Tampering**
  - Message transmissions can be modified and retransmitted undetectably
- **Repudiation**
  - Sender / receiver may not be accountable for an exchange of information.
- **Information Disclosure**
  - Lack of confidentiality, identity protection.
- **Denial of Service**
  - An unauthenticated outsider station can disrupt legitimate communication, e.g., by sending disassociates (to clients/AP).

802.11i RSN Security Services

- **Upper Level Source Authentication (above)**
  - 802.1X (EAPOL)
    - Star/hub-spoke: for station (client) -AP (in a BSS)
    - Peer-peer: station-station (in ad-hoc mode)
    - May use multiple authentication methods. Typically
      - Typically TLS (two-way TLS authentication): EAP-TLS
      - EAP-TTLS, EAP-PEAP
        - » One-way TLS authentication with TLS-protected client authentication
- **Data confidentiality, Privacy**
  - Encryption performed at the MPDU level
- **Message Integrity**
  - Also performed at the MPDU level
  - MIC is done over MAC header and the payload - omitting mutable fields
- **Replay Detection**
  - Uses sequence counters with protected datagrams
- **DoS Protection**

RSN Security Model

- **IEEE 802.1X used for upper layer authentication**
  - Also used for key management: temporal key distribution.
- **Three privacy protocols supported :**
  - TKIP (legacy equipment), WRAP and CCMP protocols: CCMP is of interest here.
  - All above use 802.1X for authentication and key distribution.
- **<802.1X, CCMP> extended to IBSS (adhoc network) security.**
- **Confidentiality, integrity of data protected, marginal protection for DoS,**
  - Unicast & Multicast security.
- **Control messages not protected.**
  - Some management messages protected (disassociate, de-authenticate)

Key Management (1)

- **Pairwise set of keys for unicast traffic**
  - A set of five keys per client-AP pair: two EAPOL Keys; and three transient keys
  - Transient keys exchanged in a four-way handshake of EAPOL key messages.
- **Group keyset for multicast traffic**
  - Three keys per BSS.
  - Conveyed to client in a two-way handshake.
- **At the end of above exchanges, secure data traffic is enabled by AP.**

Key Management (2)

- **Pairwise Keys: Unicast data**
  - Master Key (PMK): generated out of 802.1X auth. Exchange
  - Five keys are derived with master key (PMK)
  - Transient Keys (PTK pairwise transient keys)
    - A TEK: encryption
    - 2 MIC's (TMK): for message integrity (upstream, downstream)
    - EAPOL-KEK (encryption), EAPOL-KMK (message integrity)

- **Group Keys**
  - Used for multicast, broadcast
  - The keys are shared common across the BSS by the AP.
  - Group Master Key (generated by AP)
  - Group Transient Key (GTK): derived from GMK
    - Derive three keys: 2 MIC keys (GTMK) and one (GTEK)
  - In very marginal TSN's the GTK is used for encryption
    - Boils down to old WEP-level security vulnerability.

Security for 802.11 IBSS

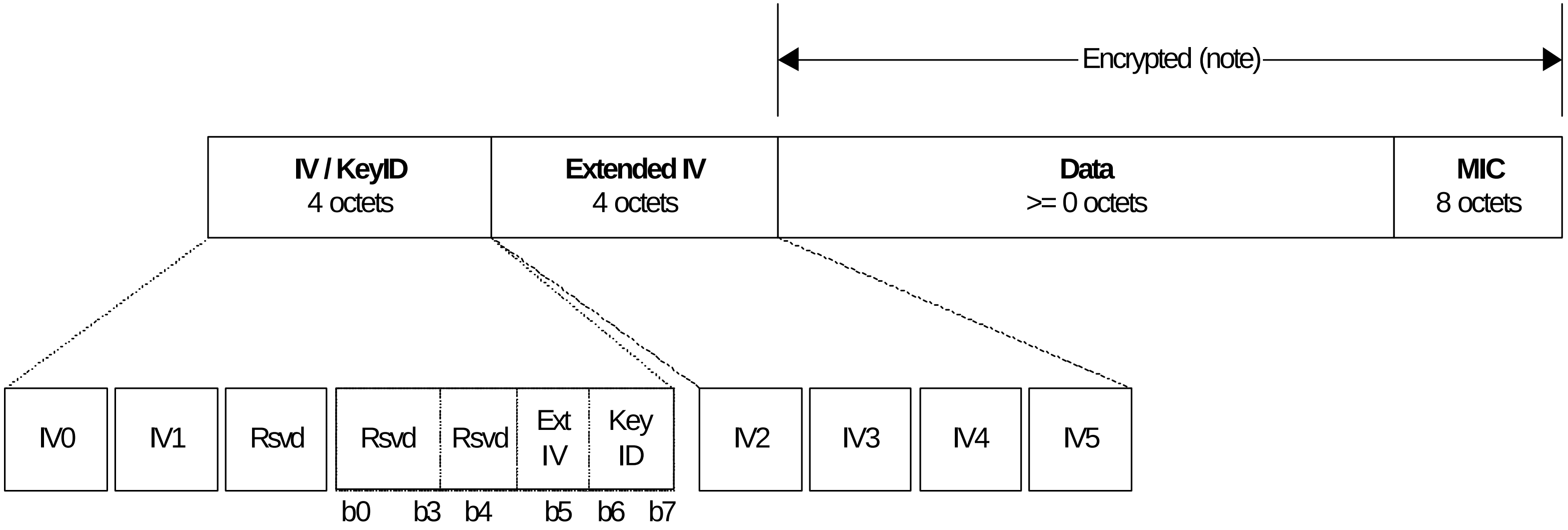
- **Each station now treated as a <AP, station, AS> to rest of members**
  - A model very identical to ESS is applied each way.

- **Pairwise Keys: Same approach as for ESS but with subtle difference as below:**
  - Each pair of stations perform key exchange separately in each direction (since each acts as supplicant in turn)
  - Therefore two sets of pairwise keys are produced
  - Unicast messages are encrypted with key from the Authenticator with the lower MAC address

- **Group Keys**
  - Each STA uses its own group key for its multicast transmissions – this is same concept as in ESS AP case.
  - Consider STAx. All other STAs that want to communicate with STAx must first exchange keys. STAx sends its multicasts using its own group key. All valid STAs can understand if they know STAx's group key.
  - This is true for every STA – it has own group key and shares it only with those STAs that exchange pairwise key.
  - Method for creating and sending group key is the same as for ESS case (AP to STA)

802.11i CCMP MAC frame

For the bit-conscious:



Note: The encipherment process has expanded the original MPDU size by 16 octets, 4 for the IV / Key ID field, 4 for the extended IV field and 8 for the Message Integrity Code (MIC).

- **MIC calculated over MAC header (except some mutable fields and IV) and data**
- **Encryption is performed over data & MIC trailer**

IEEE 802.15 WPAN

- **AdHoc networking: open comm. medium**
  - devices may or may not have ever met before
  - Piconet is a basic unit: star-network topology
- **No connection to external networks assumed**
  - the normal case for WPAN
- **Short duration association**
- **Assumed that devices external to the network can both listen on and transmit data**
  - Upstream & downstream
- **Piconet controller (PNC) is the security coordinator – normally the master of the Piconet**

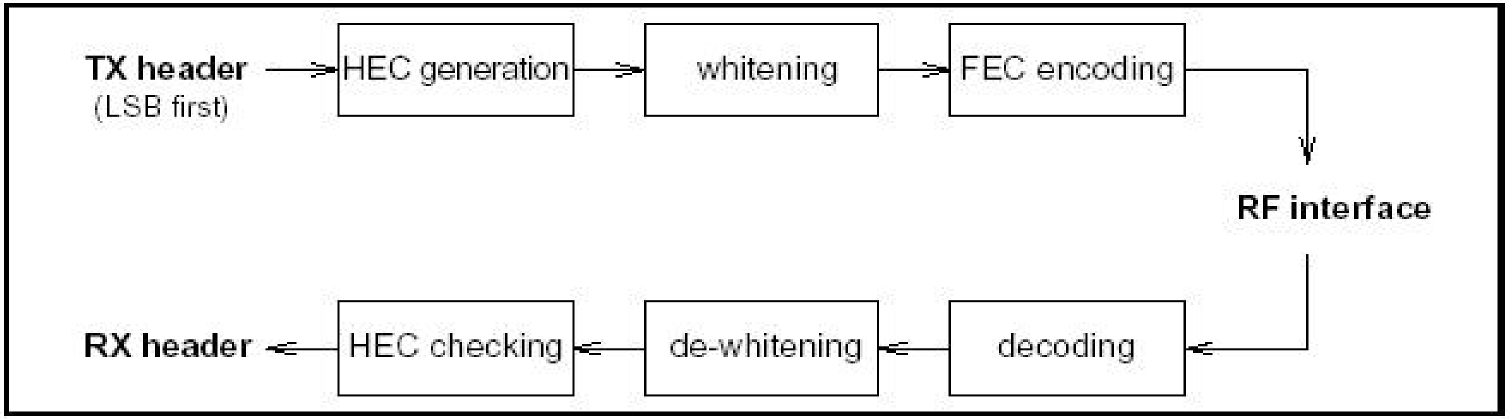
802.15 Threat Model

- **Threats in 802.15 very similar to those of 802.11**
  - Hub-like wireless medium where
    - a device in range can listen in on communication between two parties
      - device can pose a man-in-the-middle threat
      - Can fake a PNC or a device.
- **Non-goals (threats to protect from)**
  - Denial of service
  - Individual source authentication on group messages
  - message authentication (data origin and integrity)
  - Traffic analysis
- **Two security architectures involved in 802.15**
  - Bluetooth (802.15.1)
  - 802.15.3 (high-data rate WPAN)

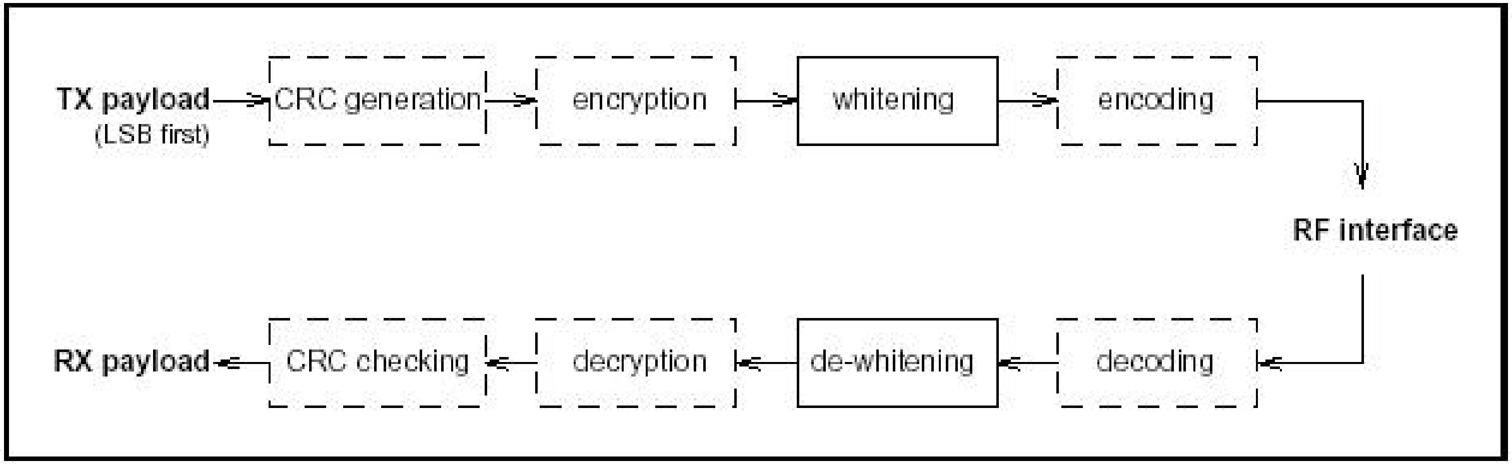
Threat Assumptions

- **Computational capabilities**: It is assumed that the attacker has state of the art technologies to perform rapid computations.
- **Listening capabilities**: It is assumed that the attacker is within listening range of the DEVs in the piconet and understands the communication mechanism.
- **Broadcast capabilities**: It is assumed that the attacker has sophisticated broadcasting equipment that is able to synchronize with the piconet and transmit data for the DEVs in the piconet at the appropriate time.
- **Security setup**: The security setup for the DEVs occurs either before entry into the piconet or after the piconet has been established.No assumptions are made about the presence of attackers during security setup.

802.15.1 Header ‘Protection’



Header bit processes. : Reliability & security of header by HEC, whitening



Payload bit processes. : Reliability & security of payload by whitening, encryption

802.15.1 (Bluetooth) Security

- **Trust establishment is thru' public/private keypair related to each device**
- **Link Key is the basis for end-entity authentication**
  - Four types of keys map to link key based on the phase of initialization
    - Init Key: K_{init}: used during first establishment of Link Key
    - Master Key: K_{master}: Used by master (PNC) to broadcast/multi-cast
    - Unit Key: K_{unit}: derived based on a unit's own credentials.
      - used by resource-starved devices: one for all piconet.
    - Combination Key: K_{AB}
      - Derived between two parties using combined credential exchange
  - Derive encryption key from current link key at the end of authentication
- **Encryption performed over the data payload.**
  - No message authentication involved.

802.15.3 Security Services

- **Trust establishment**
- **Authentication of devices**
  - TLS-like public key mutual authentication between PNC and device; or peer-peer between devices
- **Key management**
  - Using public keys or digital certificates during auth.
  - Authentication is basis for establishing comm. keys for encryption and integrity (below).
- **Freshness detection (against replay)**
  - Liveliness of transmissions using counters
- **Message Integrity Protection**
  - Both data payloads and commands
- **Confidentiality, Privacy Protection as well on data payloads**

802.15.3 Security: MAC formats

Beacon Frame Format: Integrity-protected by MIC

Beacon header	Current SSID	Time token	Message Integrity Code(MIC)

Command Frame Protection Format

Cmd. header	**Current SSID**	**Time token**	**counter**	**IV**	**Encrypted payload (cmd)**	**Message Integrity Code(MIC)**

Data Frame Protection Format

Data Header	**Current SSID**	**Time Token**	**IV**	**Payload (encrypted data)**	**Message Integrity Code (MIC)**

IEEE 802.16 - WMAN (DOCSIS)

- Baseline Privacy Plus (BPI+) Interface Specification
  - Finished on March 2002 based on BPI (started 1998)
  - BPI+ adds CM authentication to BPI, SAIDs and improves encryption

- BPI+ employs X.509 version 3 digital certificates for authenticating key exchanges between the CM and CMTS
  - Key exchange messages are encrypted with 3DES with double key and message authentication adding a 20 bytes digest (RFC 2104)

- BPI+ establishes Security Associations (SAs) to encrypt traffic upstream and downstream
  - User data is encrypted with DES using a 64 bits key

- System solution - the DOCSIS system supports the remote downloading of code to its network cable modems. There are multiple levels of protection.
  - The manufacturer of the CM code always applies a digital signature to the code file
  - In addition, an MSO may later apply their code signature
  - The CM must verify both signatures with a certificate chain that extends up to the DOCSIS root before accepting a code file.

BPI+ Keys Hierarchy (1)

- RSA Public/Private Key:
  - Unique to each CM, they provide a secure way to communicate with an individual CM.
  - They are used to encrypt the Authorization Key for delivery to a specific CM.
  - A CM will keep the same RSA key pair over its entire operational lifetime.

- Authorization Key (AUTH_KEY):
  - Unique to each CM, the AUTH_KEY is sent by the CMTS to the CM once the CM has been approved for Baseline Privacy authorization.
  - The AUTH_KEY has a limited lifetime and must be periodically renewed

BPI+ Keys Hierarchy (2)

- Traffic Encryption Key (TEK): (64 bits, DES)
  - Each TEK is associated with a specific security association.
  - The cable modem must be capable of maintaining two active sets of TEK information.
  - Each TEK has a limited lifetime and must be periodically renewed.
- Key Encrypting Key (KEK): (128 bits, 3DES double 64 bit keys)
  - Derived from a CM’s AUTH_KEY
  - The KEK is used to encrypt TEKs for delivery to a CM.
- Message Authentication Keys: (RSA SHA-1)
  - Derived from a CM’s AUTH_KEY
  - Used to key the HMAC-SHA algorithm to calculate a message digest for downstream and upstream Key Request/Response messages.
  - A separate key for upstream and downstream HMAC-digest calculations

Baseline Privacy Authorization

- The CM sends an authorization request to the CMTS that includes the CM’s
  - Unique MAC address, RSA Public Key, and one or more assigned unicast SIDs (first assigned during initialization).
- The CMTS will verify the CM’s service authorization.
- If the CM is approved for authorization, the CMTS will send an authorization reply including a list of assigned unicast and multicast SIDs, and an encrypted authorization key (AUTH_KEY) unique to the cable modem.
- The AUTH_KEY is RSA encrypted with the CM’s public key.
- Once the cable modem has been authorized, the CM shall initiate a TEK (Traffic Encryption Key) State Machine for each SID

Baseline Privacy Authorization

- The CM can now request and obtain traffic keys from the CMTS.
  - Traffic Keys are used to encrypt packet data traffic between the CM and CMTS.
  - To obtain TEKs, the CM will send a key request, requesting a TEK for each SID.
  - Key requests are authenticated using a Baseline Privacy HMAC digest.

- In response to key requests from an authorized cable modem, the CMTS will
  - Send key reply messages to the cable modem that contain an encrypted TEK, initialization vector (IV), key sequence number, and key lifetime (in seconds).
  - The key reply message is authenticated using the HMAC digest and an HMAC key derived from the CM's authorization key.

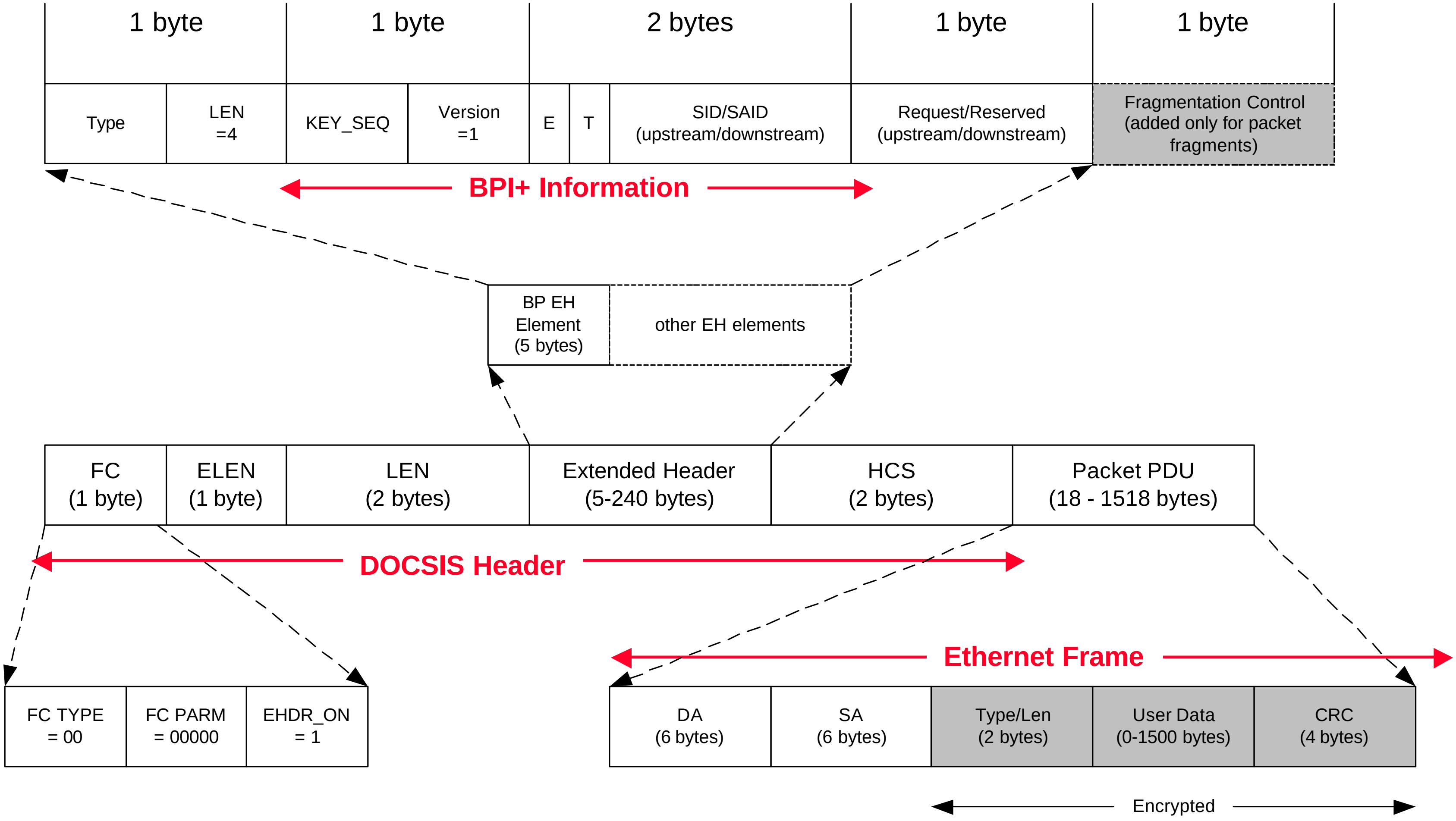
BPI+ Security Associations (SA)

- Security Associations (SAs)
  - Identified with a 14-bit Security Association ID (SAID)
  - There is a primary SAID established at registration time
  - Additional SAIDs can be established

- All traffic upstream is encrypted using Primary SAID.
  - The value used for the primary SAID is identical to the CM’s primary SID (service ID)

- On the downstream additional SAIDs are used for multicast traffic
  - IGMP management mechanisms in the CM triggers BPI+ Map Request messages that query the CMTS for the mapping of an IP multicast group address to an SA.

DOCSIS BPI+ Extended Header



FSAN G983.1- A/BPON

- **FSAN provides low level of protection for data confidentiality based on a data scrambling mechanism (Churning)**
  - It uses a 24-bit encryption key. Key update rate is at least 1 update per second per ONU.
- **Assumes a “secure” upstream channel, and hence all confidential information is generated by ONU and only transmitted in upstream**
  - ONU generates the keys and sends them to OLT
  - It prevents masquerade by ONU sending identification password to OLT on the upstream
- **Churning is used on P2P data connections on the downstream**
  - Churning is enabled or disabled per VP at its set up
- **The use of higher layer security is recommended if churning is not enough to meet the security requirements of a particular service**
- **FSAN is in the process of upgrading the definition**

G983.1- Key Change

- **G983.1 does not incurs any upstream overhead per cell transmission**
  - Key change indication is done with management messages

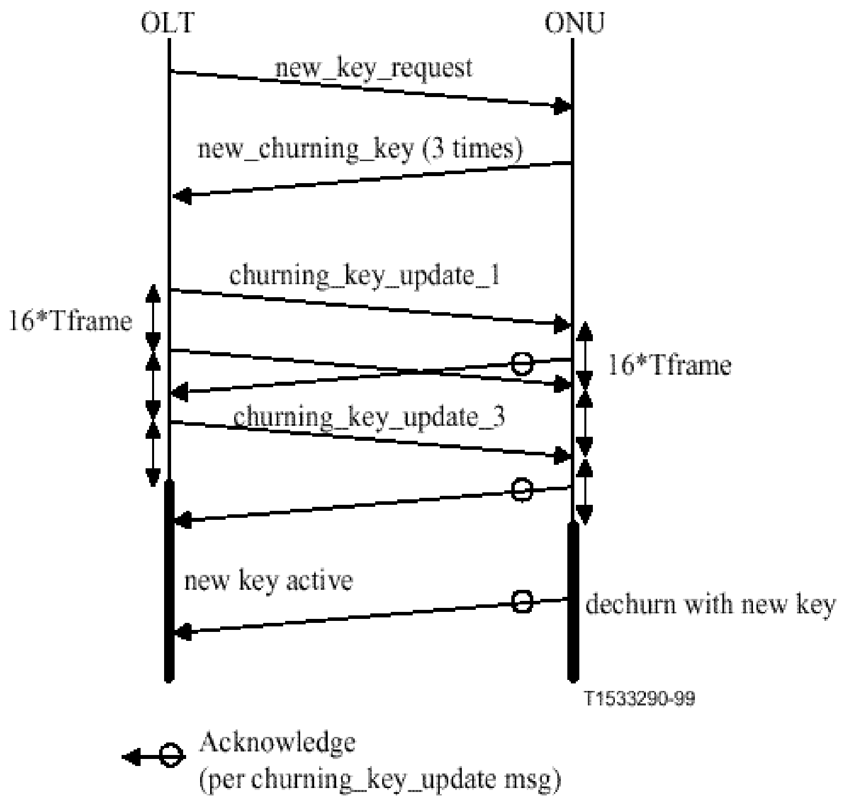


Figure 17/G.983.1 – Churning message flow

IEEE 802.10 Framework

- **A link-layer IEEE security framework for any generic medium.**
- **Threats protected against**
  - Unauthorized disclosure
  - Masquerading
  - Unauthorized data modification
  - Unauthorized resource use
- **Security Services**
  - Data confidentiality.
  - Connectionless integrity.
  - Data Origin Authentication
  - Access control.

802.10: Generic LAN threat model

- **Unauthorized resource use & spoofing/masquerading.**
  - Any station can communicate to any in the LAN
  - Any station attached to LAN can impersonate another(‘s address)
    - receive as another or transmit as someone else.

- **Unauthorized disclosure & data modification**
  - Geographic dispersion can facilitate eavesdropping and wiretap
    - Much more constrained in switched LANs
  - Before reception at the intended destination data may be modified.

- **Combinations of these threats can lead to**
  - DoS, identity theft, unauthorized disclosure, misrepresentation of data (reception and transmission), redirection of traffic (session hijack), repudiation.

802.10 Header

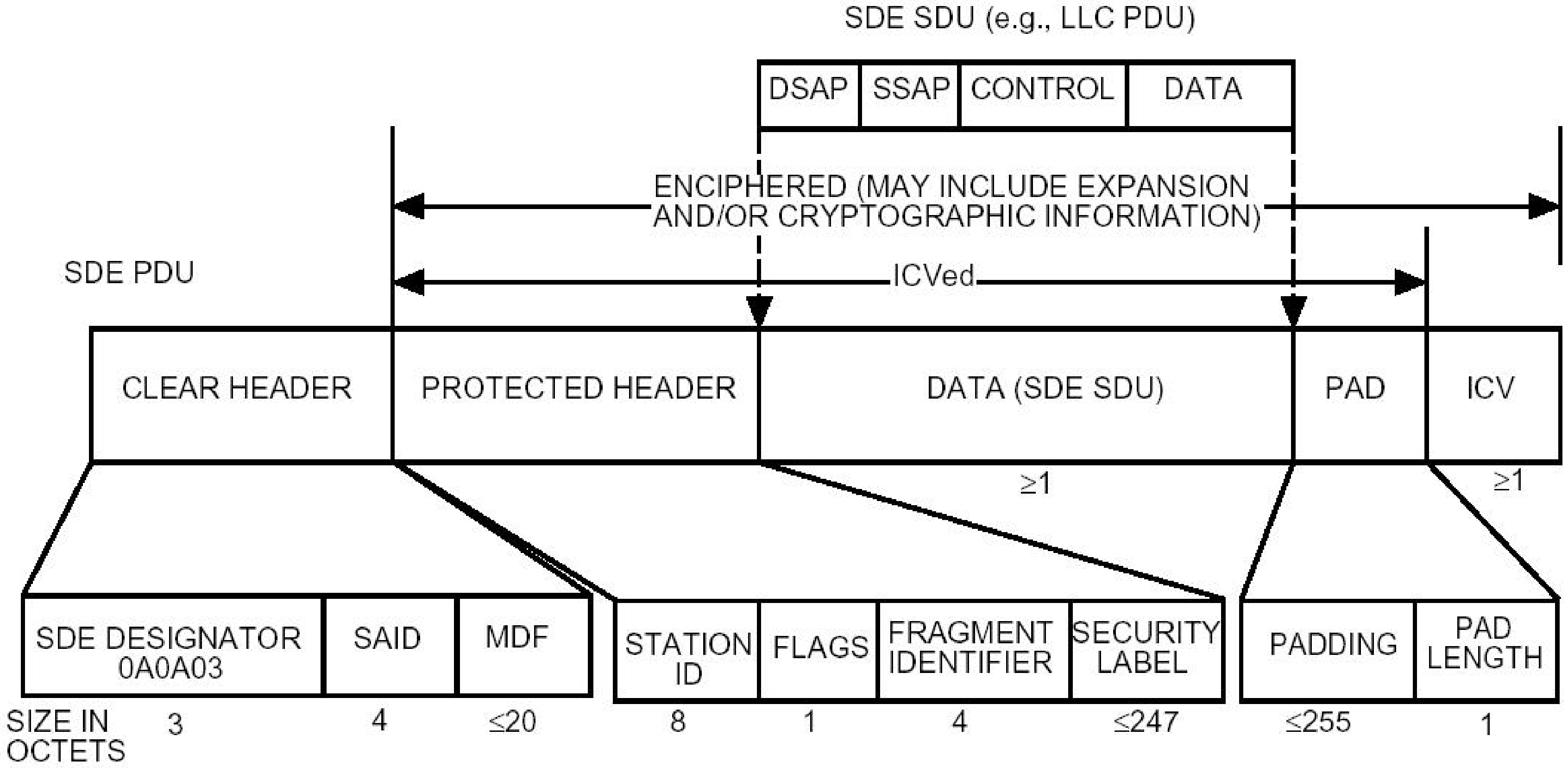


Figure 2-3—Structure of the SDE PDU

Comparison of Threats

(Need for)	802.11	802.15 .1 (BT)	802.15 .3	802.16/ DOCSIS	802.10	FSAN
Confidentiality	Ö	Ö	Ö	Up/Down	Ö	Downstrm
Authentication	Ö	Ö	Ö	CM (Up)	Ö	ONU (Up)
Msg Authentication	Ö	´ *	Ö	Ö	Ö	´
Data Integrity	Ö	´ *	Ö	Ö	Ö	´
Access Control	Ö	Ö	Ö	Ö	Ö	´
Privacy	Ö	Ö	´	Ö	Ö	Ö
Non repudiation of delivery	´	´	´	´	Ö	´
Denial of Service Protection	Ö	Ö	Ö	´	´	´

* deemed handled at PHY layer: HEC, whitening

Comparison of Mechanisms

	802.11	802.15.1	802.15.3	802.16	802.10	FSAN
Encryption	AES-CCM	**E0 (stream)**	AES-CCM	DES/3DES	ö	Churning; 24 bit key
Authentication	802.1X	**E22**	AES-CCM	CM (Up)	ö	ONU (Up)
Msg Authentication	AES-CCM	´	AES-CCM	HMAC-SHA-1 FCS	ö	´
Data Integrity	ö	´	ö	ö	ö	´
Digital Signature	X.509, PSK	´	X.509, PSK	X.509	Yes	´
Replay Detection	ö	´	ö	´	ö	´
Protected Fields	SA,DA, payload	Frame body	payload of data, mgmt	Payload + FCS	Frame payload	Only cell payload
Layer	low MAC	Low MAC	low MAC	low MAC	MAC clnt	MAC Client
Per frame OH	16(/20) byte	0 byte	~16 bytes	3 bytes	>20	0 bytes
Secure Multicast	ö	ö	ö	ö	ö	´

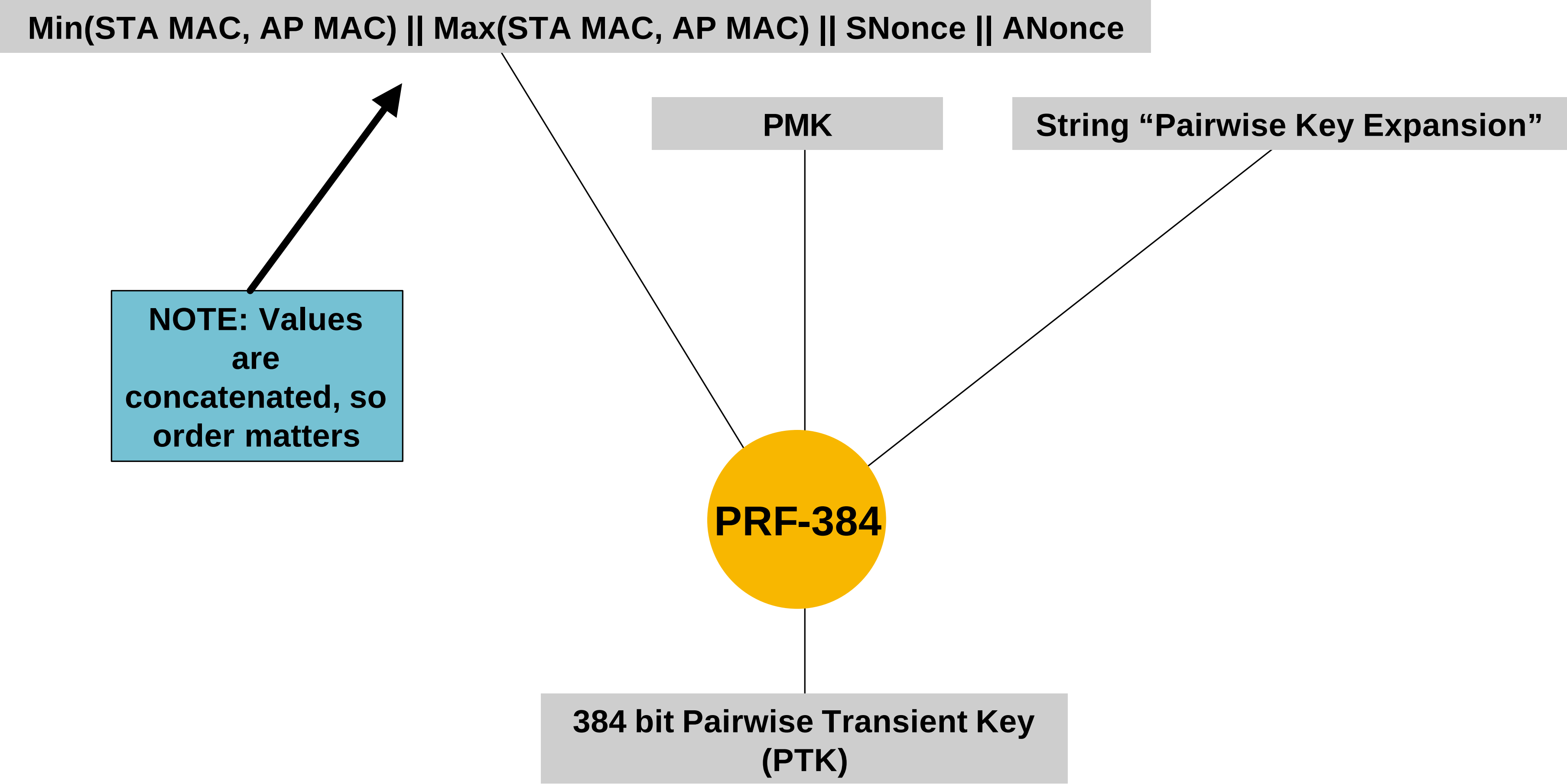
Conclusions

- **Link Security is needed for any shared subscriber access technology**
  - Mechanism is combined with access protocol
- **Ethernet must define its own security mechanism to operate in point-to-multipoint subscriber access networks**
- **It can leverage expertise and experience from other systems (802.10, 802.11i,…)**
- **If 802.10 is considered, it needs re-evaluation to ensure applicability for HW implementations**

References

- **BPI+ : http://www.cablemodem.com/downloads/specs/SP-BPI+-I09-020830.pdf**
- **FSAN: ITU-T G.983.1 Broadband optical access systems based on Passive optical networks (PON)**
- **IEEE submissions: 11-02-551r1, 11-02-499ar1, 802.11i-D2.3**
- **IEEE 802.15.3**
  - Draft standard
  - http://www.securemulticast.org/GSEC/gsec3_ietf53_Singer.pdf

The Pairwise Key Hierarchy



Min(STA MAC, AP MAC) || Max(STA MAC, AP MAC) || SNonce || ANonce

PMK

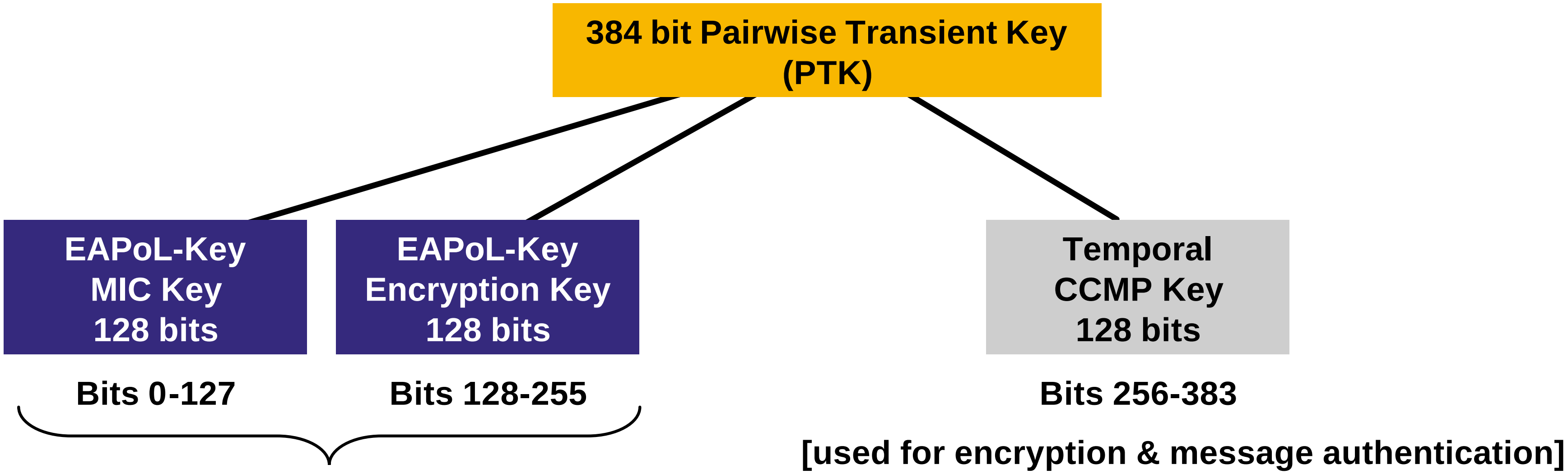
String "Pairwise Key Expansion"

NOTE: Values are concatenated, so order matters

PRF-384

384 bit Pairwise Transient Key (PTK)

The Pairwise Key Hierarchy



384 bit Pairwise Transient Key (PTK)

EAPoL-Key MIC Key 128 bits

EAPoL-Key Encryption Key 128 bits

Temporal CCMP Key 128 bits

Bits 0-127

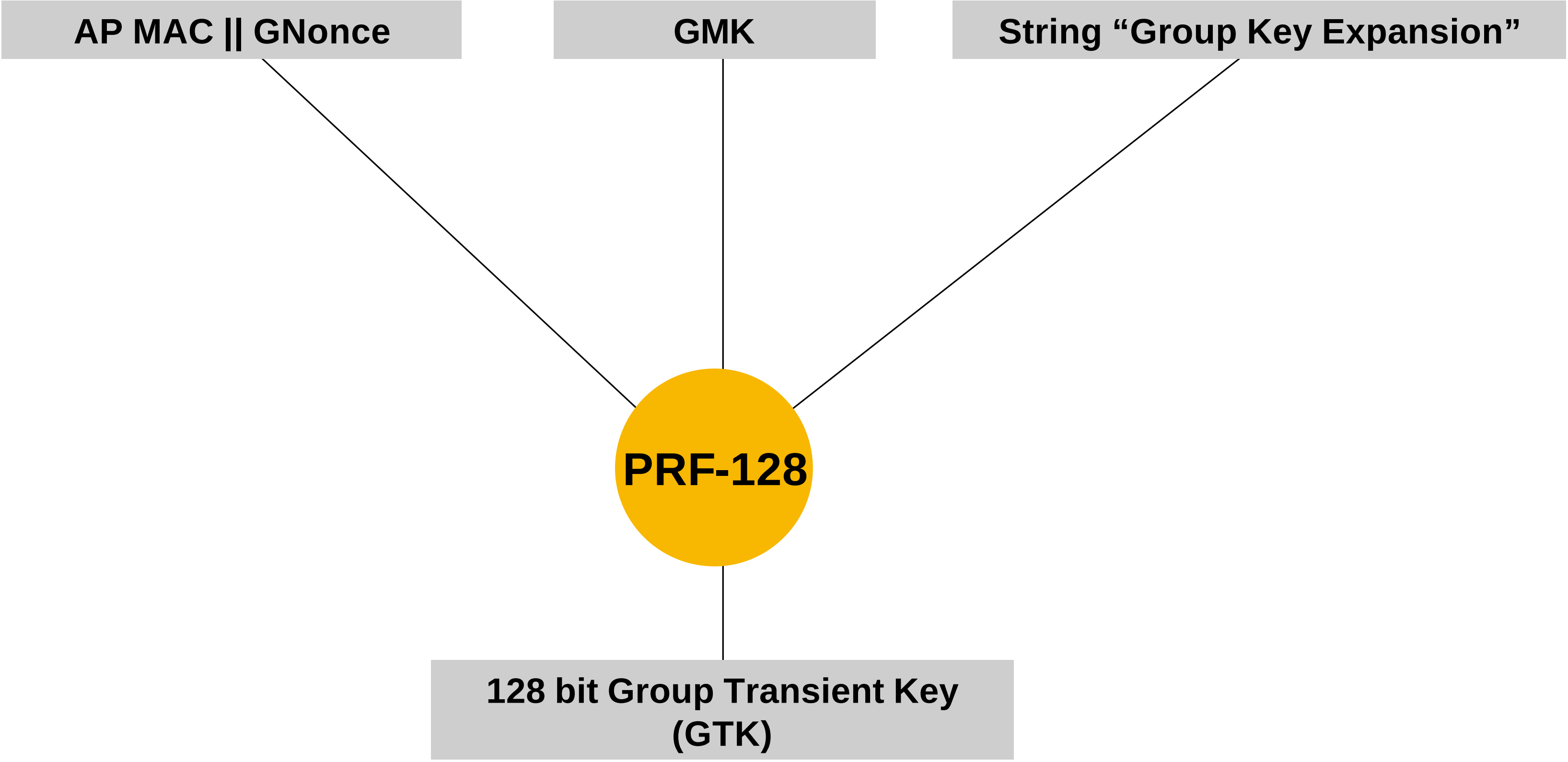
Bits 128-255

Bits 256-383

[used for encryption & message authentication]

Authentication & encryption respectively
of secure key exchange of temporal key(s)

The Group Key Hierarchy



AP MAC || GNonce

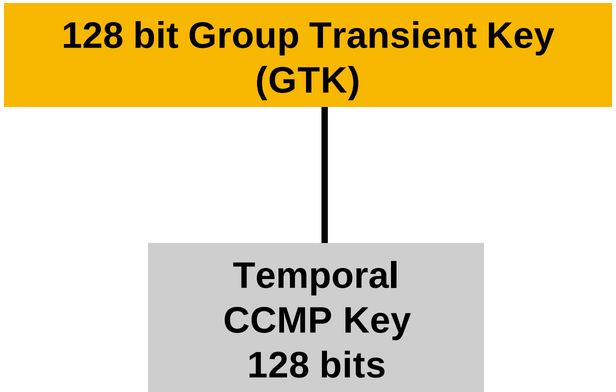
GMK

String “Group Key Expansion”

PRF-128

128 bit Group Transient Key (GTK)

The Group Key Hierarchy



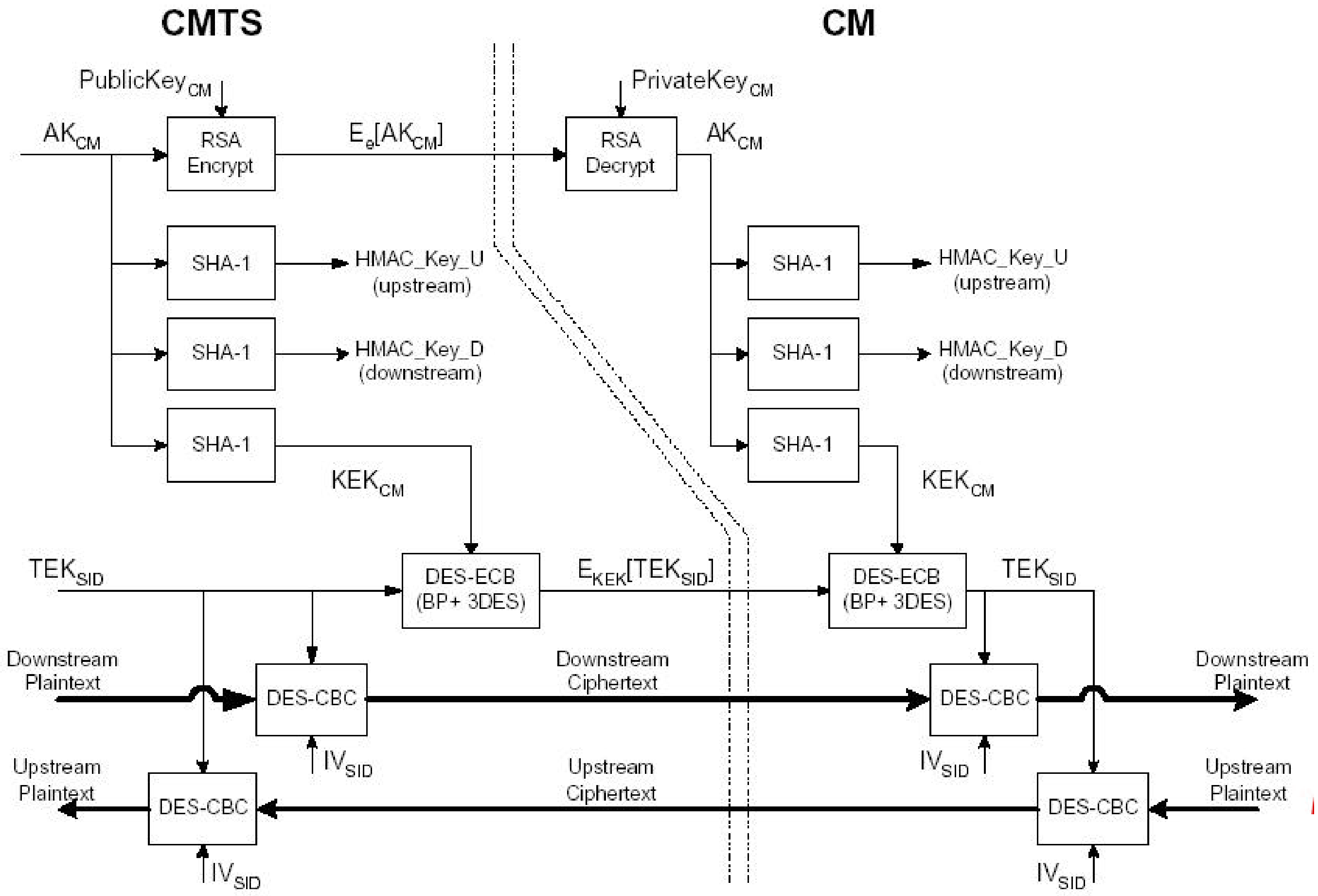
128 bit Group Transient Key (GTK)

Temporal CCMP Key 128 bits

Bits 0-127

[used for encryption & message authentication]

BPI+ Key Handling



Appendix: APON Churning

- 4.1 churning: Churning is a function which can be applied to the downstream user data from an OLT to its ONUs. Churning provides the necessary function of data scrambling and offers a low level of protection for data confidentiality. It is installed at TC layer of the ATM-PON system and can be activated for point-to-point downstream connections.
- 8.3.5.6 Churning
- Due to the multicast nature of the PON, downstream cells are churned at the TC layer with a churning key sent upstream by the ONU. The churning is performed for point to point downstream connections and churning can only be enabled or disabled per VP at its setup. The churning key update rate is at least 1 update per second per ONU. If churning is not enough for a security requirement of a provided service, a suitable encryption mechanism should be employed at a higher layer than the TC (transmission convergence) layer to provide data scrambling.

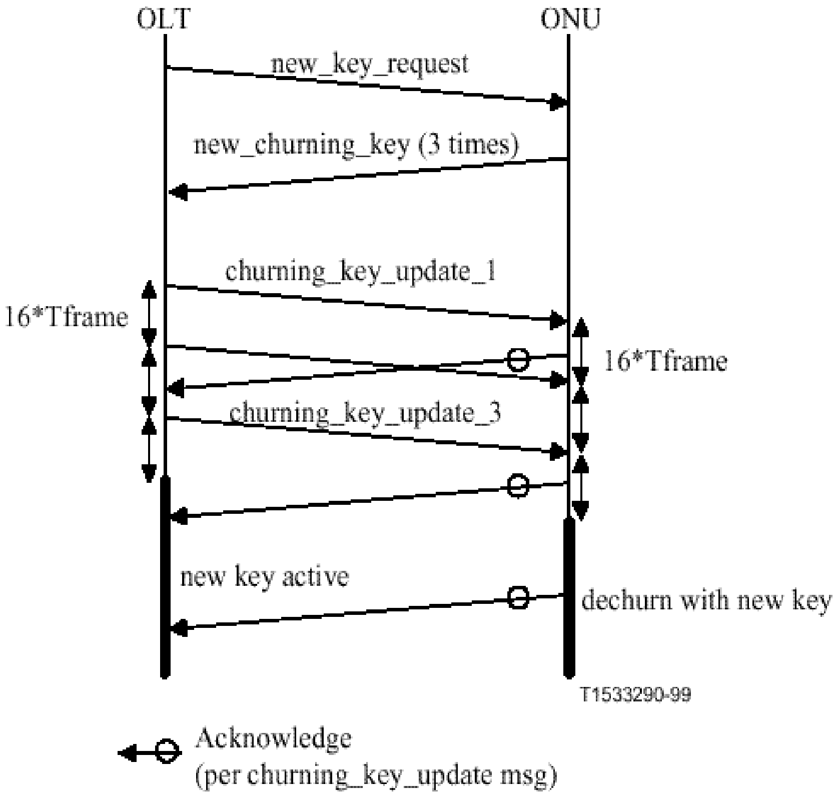


Figure 17/G.983.1 – Churning message flow

Appendix: APON Churning (2)

8.3.5.7 Verification function

- Since all the serial numbers of the ONUs can be extracted from downstream PLOAM cells as they are conveyed during the ranging protocol, a malicious user can masquerade another ONU by eavesdropping the PLOAM cells and extract all the serial numbers. The counteract this, the OLT may requests the password of the ONU. This password is only sent in upstream direction and cannot be recovered by other connected ONUs.

- When the OLT request a password, the ONU responds by sending its password three times. If it receives three identical passwords, the OLT declares this password as valid.

APON security as described in David Greenfield's story, " Passive Optical Networks" in NetworkMagazine.com, dated 5.12.2001

- Security and QoS have been hot areas in APONs. APON security is tricky because any ONT can read any cell. Like the voice network, there's no inherent security mechanism to prevent intrusion. However, the current APON specification does provide some rudimentary form of security, called scrambling. Each cell's payload runs through encryption algorithms that mix up (or “scrambles”) the data using a 24-bit encryption key. The shortness of the encryption key makes it very weak (even 40-bit keys are considered weak), but changing the encryption key's key on the fly improves the security somewhat.