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Re:	IEEE P802.16e/D5a
Abstract	There are still areas in the PKMv2 security framework that requires major corrections This contribution proposed a resolution for those major issues.
Purpose	Adoption of proposed changes into P802.16e /D5a-2004
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PKMv2 Security Framework Corrections

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1 Motivation

There are still areas in the PKMv2 security framework that requires major corrections
This contribution proposed a resolution for those major issues.

2 Overview

2.1 Remedy 1 – Key Hierarchy corrections

Proposal C802.16e-04/217r1 was accepted in session 34 but was not incorporated to the text of draft 5a.

This remedy rephrases the previous contribution and creates a well defined set of security contexts and a clear key hierarchy for use in PKMv2. The approach adapts the PMK1 key material and key deriving methodologies to achieve backward compatibility.

Some modifications were made to the original contribution.
The changes added to this contribution are:

- a group message authentication (H/OMAC) was created. The purpose is to ensure the authenticity of multicast management messages (GKEK transmission for instance).
- EIK and EEK were removed. EIK and EEK are used to encrypt the EAP exchange. 1) the EAP exchange is by definition secure and encrypted by standard, thus these keys are redundant. 2) these keys were not defined in case RSA authorization was not used (no PAK available for the derivation).
- EAK is introduced. EAK is an intermediate key created for mobility purposes mainly. This key may be common to several BSs (key-zone) and may be generated in a separate network entity. So that the whole time-consuming EAP exchange may not be necessary at each hand-over.
- Authorization Association (AA) is replaced by the AK context. The AA was defined without support for EAP only authorization. The AAID was defined by using mutual authorization products that is not available when this process is not executed. Therefore a more general AK context was defined and some variables were added for reply attack protection.
- GEKEKEK was removed. GKEK is the key encrypting the GTEK multicast transmission. GKEK is randomly generated in the BS, encrypted with MSS's KEK and transmitted to each MSS in the group. Since GKEK is the same for all MSSs in the group, each of them receive this way the cipher for each MSS and the plaintext which is the key itself. However it is virtually impossible to find back the key knowing the plaintext and the AES encrypted cipher. So that GKEKEK is not necessary.

Modification Details
In PKMv2, certificated RSA mutual authorization and EAP authentication can be used independently. That is, at capabilities negotiation, the MSS notify to the BS which mode is supported, and the BS decides which

authorization model will be adopted and can choose to use only RSA authorization, EAP authentication or both. In each of these 3 options, the key material is derived differently.

2.2 Remedy 2 – OMAC calculation correction

There are two TLV types by which OMAC is used in the standard: one is the OMAC tuple used in management messages and the other is a bare OMAC digest used only in PKM messages. The OMAC tuple and digest as defined in version 16e_D5a do not provide ample protection against replay attacks of the messages they are meant to protect. The purpose of this contribution is to add a 4byte packet counter that is part of the OMAC key context and computed in the OMAC digest to protect against replay attacks of management message. If an MSS or BS receive a MAC message with an OMAC tuple or digest with a packet counter number that is not greater than the previous message received on the same CID they will drop that message.

In the OMAC TLVs add a 4 byte Packet Number (PN) field to be added to both the digest and the tuple. This field will be sequentially updated on every MAC management packet sent with OMAC digest or tuple. The context of the field will be updated in the UL and the DL by the MSS and the BS respectively, each in it s own context (i.e. – the MSS will maintain a separate context than the BS and the PN in UL will increment independently of the PN in the DL). Multicast CID messages will also maintain their own OMAC context with a separate PN.
To ensure the uniqueness of the PN, the MSS or the BS must perform re-authentication and acquire a new AK context before the PN rolls over.
The PN will be added to the OMAC digest calculation and the OMAC_TLV attributes will be removed from the calculation. Removing the OMAC_TLV attributes is due to the explicit inclusion of the OMAC sequence id and the OMAC PN in the digest description.
The frame number will also be removed from the OMAC calculation

2.3 Remedy 3 – 3 Way handshake and TEK exchange corrections

During initial network entry or upon handoff when shared AK has been established, the BS and SS must: -

- Establish the liveliness of Authorization Key (AK). The AK is used:
  - to derive a hash key that's used for link management messages
  - to derive a Key Encryption Key for transporting the actual traffic encryption keys
- Negotiate cryptographic capabilities and distribute an SAID list to the SS
- In case of network-entry and HO, generate fresh TEKs for the SAs that were active on the previous severing BS

The number of roundtrips between BS and MSS to perform all the above exchanges greatly impacts the over all time taken to complete the handoff and re-start the subscriber's application level flows. This contribution proposes to perform all the above within a modified 3-way handshake transaction. First two messages of the proposed 3-way handshake protocol are mandatory while the third message is optional. An implementation thus has the choice to just use the first two messages i.e. a 2-way handshake to shorten the HO time or go for the complete 3-way handshake which is proven secure under the Bellare-Rogaway model.

2.4 Remedy 4 – Pre-authentication support

The authentication process of an SS with the authentication server (e.g. AAA) may take a prolonged amount of time. In 802.16D, this is not a real problem since this task is performed infrequently. In 802.16E, though, the mobility of the MSS will make it work with many BS over a short period. It will have to authenticate with as many BS's and may therefore lose some data and service continuity in the process. The pre-authentication feature is supposed to fix this problem. However, this feature as it is defined currently (P80216e_D5a) relies on an EAP protocol not yet approved and is not compatible with previous versions of the EAP protocol. This

contribution proposes a way to send an EAP method to a BS (authenticator) through another BS (Serving BS) from the MSS (supplicant) and back, and effectively tunnel the EAP method through the serving BS. All this can be done at a non-critical time with all the neighbor BS's while the link with the serving BS is still good. The purpose is to shorten the hand-over procedure and thus minimize the lost data and delay at this moment. Additionally, there is a need for the MSS especially in pre-authentication, to initiate the EAP authentication and make the BS poll it.

1. Details

Two MAC management messages are added: PKMR-REQ and PKMR-RSP for Privacy Key Management Remote. These messages are similar to PKM-REQ and PKM-RSP respectively but the serving BS when receiving them will only verify the signature (OMAC or HMAC) and, if valid, forward the message to the target BS.

The general model is illustrated in figure 1.

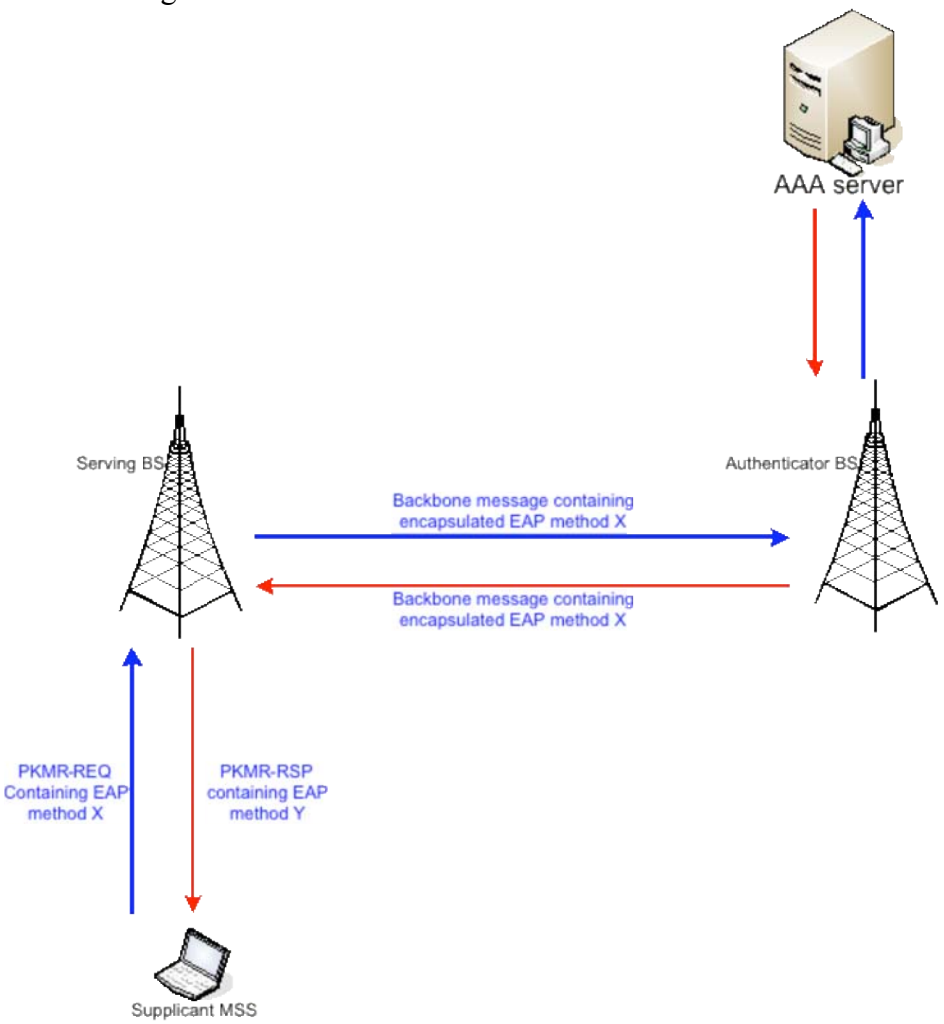


Figure 1

A new type is added to both the PKM-REQ and PKMR-REQ for the MSS to start the EAP authentication

2.5 Remedy 5 – HO optimization support

Draft 802.16D5a defines some optimizations to the HO process using an Optimization TLV.

Among these optimizations, there is a bit that can indicate the MSS it can skip PKM stage in the network-entry after HO.
There is no definition how security is established in this case but the hidden assumption is that the entire security context (keys and other parameters) is transferred from source BS to target BS in the back-bone.
This security context sharing is considered not secure enough.
This contribution supply mechanisms to establish and maintain a unique security context between the MSS and the target BS while still connected to the source BS and by this allowing skipping of PKM steps in network re-entry while maintaining high level of security.

In order to achive this goal, this contribution defines the following:
a) A key zone, which authentication with all BSs in it, can be derived from a common PMK.
b) A capability bit for the SS to determine if a target BS supports pre-authentication.
c) A configuration bit that tells the MSS if he can obtain authentication with TBS from the current PMK he uses.
d) A configuration bit that tells the MSS if a Target BS which belongs to another key-zone still maintained an authentication context with it
e) A configuration bit to tell the MSS if he can use its existing TEKs with the potential target BS(s) after handoff.

Given the above knowledge, an MSS can get information about his authentication status with tharget BS and decide if he can and wishes to obtain authentication with target BS in advance or if full EAP authentication is needed upon HO.
By being able to skip full EAP authentication upon HO, the overall HO duration is greatly reduced.

2.6 Remedy 6 – Mutual Authorization support

Mutual Authorization as defined in 802.16e_D5 has to be updated from two reasons: the first is some mistakes/incoherencies with other parts of the security suite and the other is that although the contribution 229r1 was accepted in session 32, it was not fully integrated into the standard.
This contribution defines the text that should be inserted into 802.16e in order to align the standard with the original changes needed in the original contribution and include the updates here.
In general, the mutual certificate exchange in PKMv2 is defined as follows:

auth_req: SS -> BS: SS-Random | Cert(SS) | Security suites Primary SAiD(equalsBasic CID)
auth_reply: BS -> SS: SS-Random | BS-Random | RSA-OAEP-Encrypt(PubKey(SS),PAK | Id(SS)) | Lifetime | PAKSeqNo | SAIDList | Cert(BS) | Sig(BS)
auth_ack: SS -> BS: BS-Random | SS_MAC_Address | OMAC (Pre-Auth-Key, BS_Random | SS_MAC_Address)

The PAK (Primary Authorization Key) is generated as a cryptographically strong random number in the BS and transmitted to the SS, encrypted with RSA during the above PKMv2 mutual authorization exchange.
The following are defined in this proposal:
• The auth-req/rsp/ack messages
• A BS certificate

2.7 Remedy 7 – Authorization Policy Support Negotiation

The Authorization Policy Support field indicates some parameters about the authorization authentication protocol supported by the station. It is a bitfield where each field indicates a feature supported by the station. Since it is a bitfield any feature can be supported or not. There is also a PKM version support field that is independent from the previous field. However many combinations of this bitfield are not possible and therefore

superfluous. This contribution proposes a way to make the number of redundant combinations lower. There is however a condition to be backward compatible to 802.16d.

1. **Details**

There are only a few number of combinations supported in the protocol:
PKMv1 RSA 1-way
PKMv1 EAP
PKMv2 RSA 2-way
PKMv2 EAP
PKMv2 EAP+RSA 2-way

The Mutual Auth./Unidirectional Auth. Bit is therefore not necessary since it is determined by the PKM version. We propose to remove it.

Furthermore, the OMAC/HMAC bit is a not feature absent/present bit. To correct this we make it an OMAC feature bit. Implicitly, since HMAC is the default, it means that if the OMAC bit is off, then HMAC is supported.

We leave the RSA and EAP bits although not all the combinations can exist, but we add some explicit instructions in the standard.

3 Text Change

3.1 Remedy 1 – Key Hierarchy corrections

[Insert after 7.2.2.1 the following text]

7.2.2.2 Key Derivation

The PKMv2 key hierarchy defines what keys are present in the system how keys they are generated.
Since there are two authentication schemes, one based on RSA and one based on EAP, there are two primary sources of keying material.

The keys used to protect unicast and multicast traffic are derived from source key material generated by the authentication and authorization processes. The authorization process yields the Primary AK (PAK) and the EAP based authentication process yields the EAP AK (EAK). Keys used to protect MBS traffic are derived from the MBSAK, which is supplied by means outside the scope of this specification. These keys form the roots of the key hierarchy.

All PKMv2 key derivations are based on the Dot16KDF algorithm as defined in 7.x.x.x Dot16KDF.

7.2.2.2.1 Certificated RSA authorization:

The PAK (Primary Authorization Key) is sent by the BS to the MSS encrypted with the public key from the certificate.

PAK is 160 bits long.
PAK will be used to generate the AK (see below) if RSA authorization was used.

7.2.2.2.2 EAP authentication

The product of the EAP exchange which is transferred to 802.16 layer is the AAA-key. This key is derived (or may be equivalent to the 512-bits MSK). This key is known to the AAA server, to the BS authenticator (transferred from AAA server) and to the MSS. The MSS and the authenticator derive a PMK (Pairwise Master Key) by truncating the AAA-key after 160 bits.

The PMK derivation from the AAA-key :

PMK = truncate (AAA-key,160)

If more keying material is needed for future link ciphers, the keylength of the PMK may be increased.

The next derivation step creates a key which is unique between the BS and SS called EAK (EAP authentication key).
This key is created by the SS and the authenticator and transferred from the authenticator to the BS.
The purpose of this key is to allow an authenticator which is not collocated with the BS and serves more than one BS using a single PMK.

The EAK will be used to generate the AK (see below) in case EAP authentication was used.
The EAK will be derived from PMK,BSID and SSID:

EAK <= Dot16KDF (PMK, SSID | BSID | "EAK", 160)

7.2.2.2.3 Authorization Key (AK) derivation

The AK will be derived by the BS and the MSS from the EAK (from EAP exchange) and the PAK (from RSA exchange). If one of these keys is not available, the AK will be equal to the other key.
Note that PAK can be used only in initial network entry. In cases of HO and re-authentication: Only EAP keys are applicable.

```
If (PAK and EAK)
        AK <= Dot16KDF (EAK, SSID | BSID | PAK | "AK", 160)
Else
        If (PAK)
                AK <= PAK
        Else                    // EAK only
                AK <= EAK
        Endif
Endif
```

7.2.2.2.4 Key Encryption Key (KEK) derivation

KEK is derived directly from the AK
The Key Encryption Key (KEK) is defined in 7.2.2.2.9 with the OMAC/HMAC definition

KEK is used to encrypt the TEKs, GKEK and all other keys sent by the BS to MSS in unicast message.

7.2.2.2.5 Group Key Encryption Key (GKEK) derivation

GKEK is randomly generated at the BS and transmitted to the MSS encrypted with the KEK. There is one GKEK per Group Security Association.
GKEK is used to encrypt the GTEKs sent in multicast messages by the BS to the MSSs in the same multicast group.

7.2.2.2.6 Traffic Encryption Key (TEK)

The TEK is generated as a random number is the BS and is encrypted using AES_KEY_WRAP, keyed with the KEK and transferred between BS and SS in the TEK exchange.

7.2.2.2.7 Group Traffic Encryption Key (GTEK)

The GTEK is used to encrypt multicast data packets and it is shared between all MSSs that belong to the multicast group. There are 2 GTEKs per GSA.
The GTEK is randomly generated at the BS and is encrypted using AES_KEY_WRAP and transmitted to the MSS in multicast or unicast messages. In multicast the message will be encrypted by the GKEK. In unicast, it will be encrypted by the KEK.
.

7.2.2.2.8 MBS Transport Key (MTK)

The generation and transport of the MAK (MBS AK) is outside the scope of the 802.16 standard. It is provided through means defined at higher layers. However the keying is used in the link cipher, therefore its existence needs to be defined in layer 2.

The MTK is used to protect transport data. It is defined as follows:
MTK <= Dot16KDF(MAK, MGTEK, 128)

7.2.2.2.9 Message authentication keys (OMAC/HMAC) and KEK derivation

MAC (message authentication code) keys are used to sign management messages in order to validate the authenticity of these messages. The MAC to be used is negotiated at SS Basic Capabilities negotiation.
There is a different key for UL and DL messages and also a OMAC key for each multicast group (this is DL direction only).

The keys used for OMAC calculation and for KEK are as follows:

OMAC_KEY_U | OMAC_KEY_D | KEK <= Dot16KDF(AK, SSID | BSID | “OMAC_KEYS+KEK”, 384)
OMAC_KEY_GD <= Dot16KDF(GKEK, ”GROUP OMAC KEY”,128) (used for group management messages MAC)

The keys used for HMAC calculation and for KEK are as follows:

HMAC_KEY_U | HMAC_KEY_D | KEK <= Dot16KDF(AK, SSID | BSID | “HMAC_KEYS+KEK”, 448)
HMAC_KEY_GD <= Dot16KDF(GKEK, ”GROUP HMAC KEY”, 160) (used for group management messages MAC)

7.2.2.2.10 Key hierarchy

Figure xx1 outlines the process to calculate the AK when the authorization process has taken place, but where the EAP based authentication process hasn't taken place, or the EAP method used has not yielded an AAA-key:

Figure xx1: AK with RSA only authorization process

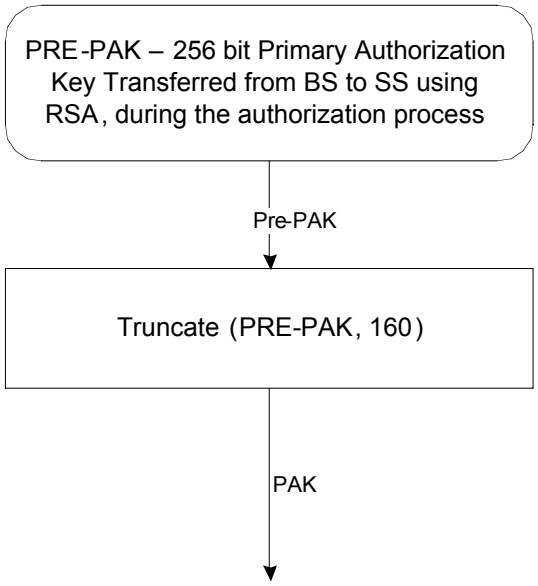


Figure xx2 outlines the process to calculate the AK when both the authorization exchange has taken place, yielding a PAK and the EAP based authentication exchange has taken place, yielding an AAA-key:

Figure xx2: AK with RSA+EAP authorization process

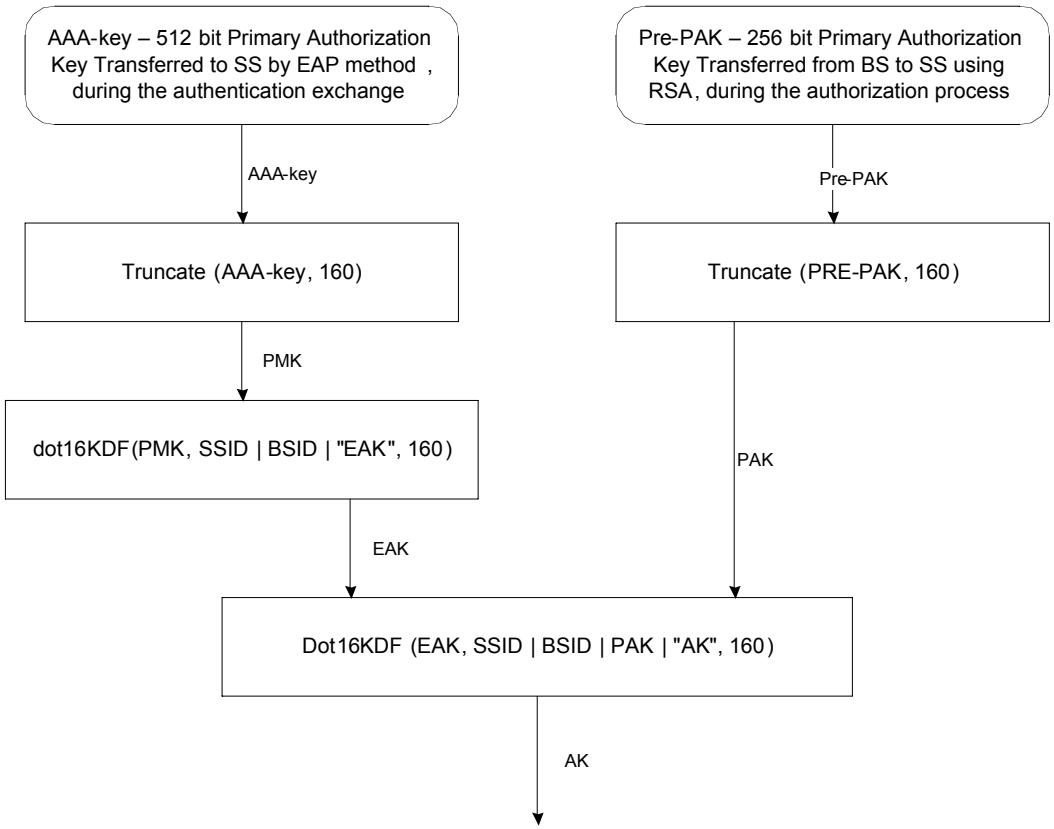


Figure xx3 outlines the process to calculate the AK when only the EAP based authentication exchange has taken place, yielding an AAA-key:

Figure xx3: AK with EAP only authentication

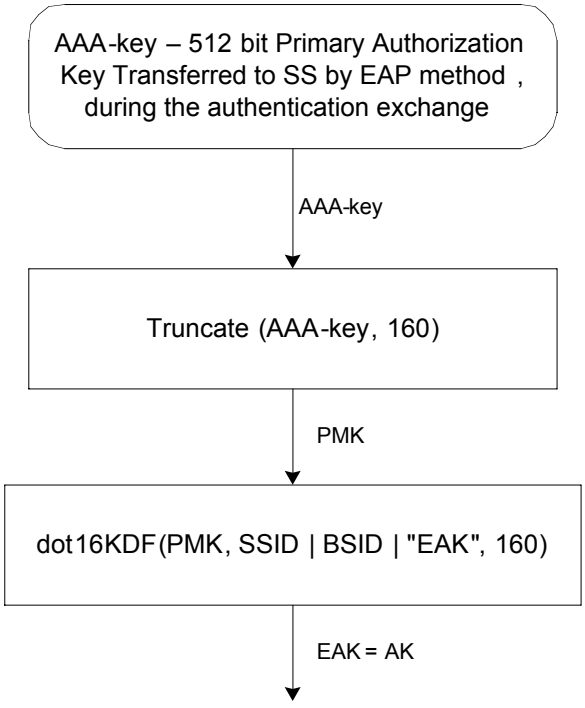


Figure xx4 outlines the unicast key hierarchy starting from the AK:

Figure xx4: AK key derivation from AK

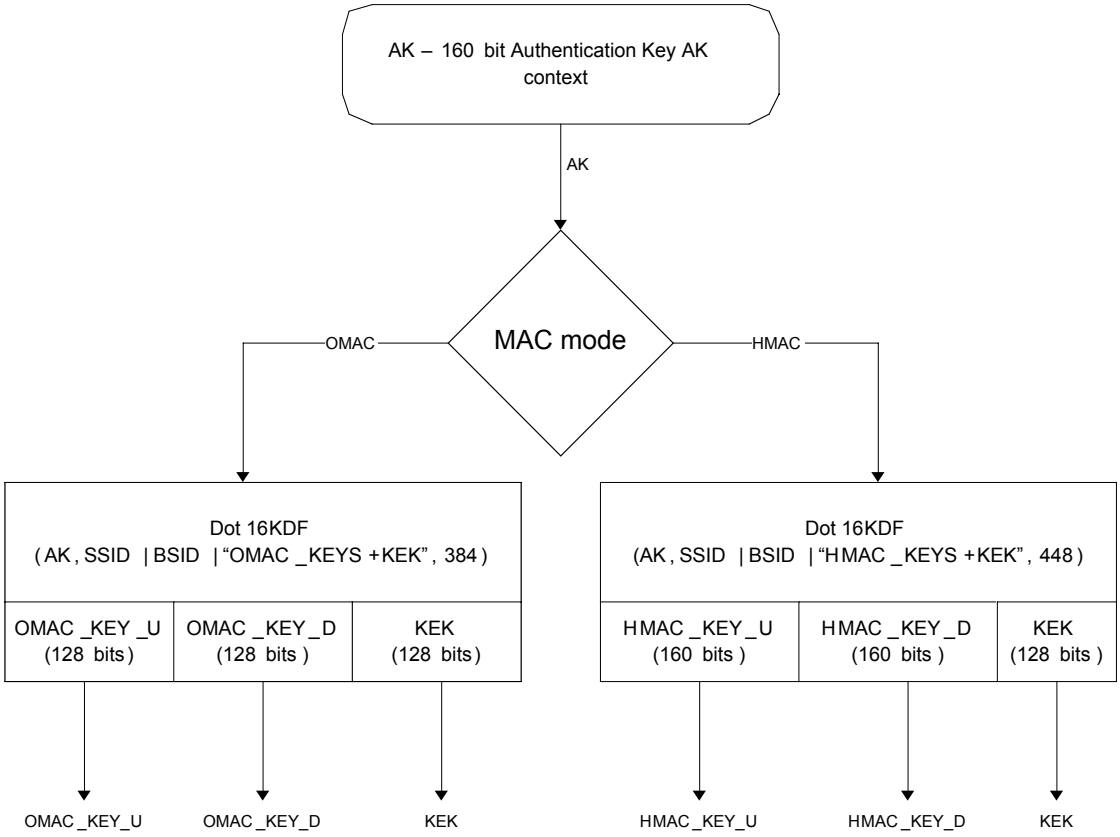
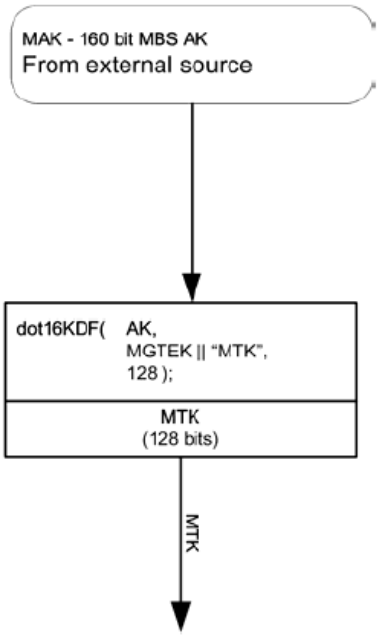


Figure xx5 outlines the MBS key hierarchies starting from the MAK:

Figure xx5: AK key derivation from AK



7.2.2.3 Associations

Keying material is held within associations. There are three types of association: The security associations (SA) that maintain keying material for unicast connections, group security associations (GSA) that hold keying material for multicast groups and MBSGSAs which hold keying material for MBS services.

7.2.2.3.1 Security Associations

A security association contains keying material that is used to protect unicast connections. The contents of an SA are:

The SAID, a 16 bit identifier for the SA. The SAID shall be unique within a BS.
The KEK, a 128 bit key encryption key, derived from the AK.
TEK0 and TEK1, 128 bit traffic encryption keys, generated within the BS and transferred from the BS to the SS using a secure key exchange.
The TEK Lifetimes TEK0 and TEK1, a key aging lifetime value.
PN0 and PN1, 32 bit packet numbers for use by the link cipher
RxPN0 and RxPN1, 32 bit receive sequence counter, for use by the link cipher.

7.2.2.3.2 Group Security Association

The Group Security Association (GSA) contains keying material used to secure multicast groups. These are defined separately from SAs since GSA offer a lower security bound that unicast security associations, since keying material is shared between all members of the group, allowing any member of the group to forge traffic as if it came from any other member of the group.

The contents of a GSA are:

The Group Key Encryption Key (GKEK). Serves the same function as an SA KEK but for a GSA

The Group Traffic Encryption Key (GTEK). Served the same function as an SA TEK but for a GSA.

7.2.2.3.3 MBS Group Security Association

The primary keying material in the MBS Group Security Association is the MAK. This serves the same function as the AK in the Authorized Association, however the MAK is provisioned by an external entity, such as an MBS server. The MAK may be common between members of an MBS group.

The contents of an MBSGSA are:

The MAK, a 160 bit MBS AK, serves the same function as the AK but local to the MBSGSA.
The MGTEK, a 128 bit MBS Group Traffic Encryption Key, used indirectly to protect MBS traffic. It is updated more frequently that the MAK.
The MTK, MBS Traffic Key, a 128 bit key used to protect MBS traffic, derived from the MAK and MGTEK.

7.2.2.4 Security context

The security context is a set of parameters linked to a key in each hierarchy that defines the scope while the key usage is considered to be secure.

Examples of these parameters are key lifetime and counters ensuring the same encryption will not be used more than once. When the context of the key expires, a new key should be obtained to continue working.

The purpose of this section is to define the context that belongs to each key, how it is obtained and the scope of its usage.

7.2.2.4.1 AK context

The context of AK includes all the parameters connected to AK and keys derived directly from it.
When one parameter from this context expires, a new AK should be obtained in order to start a new context.
Obtaining of new AK means re-authentication – doing the whole EAP until obtaining a new PMK which (E)AK may be derived from.
Derivation of EAK key after HO is done separately in the SS and network from a common PMK , SSID and BSID. The PMK may be used to derive keys to several BSs belonging to the same key-zone.
In HO scenario, if the SS was already connected to the TBS, the derived AK will be identical to the last one, as long as the PMK stays the same.
In order to maintain security in this scenario: the context of the AK must be cached by both sides and to be used from the point it stopped, if context lost by one side, re-authentication is needed to establish new context
The AK context includes:

Parameter	Size	Usage
Primary AK (PAK)	160 bit	A key yielded from the mutual authorization exchange. Only present at initial network entry and only if the certificated RSA exchange took place, as a result of the authorization policy negotiation.
PAKID	64 bits	Arrived from the mutual authorization, present when PAK is present
PAK lifetime		Arrived from the mutual authorization, present when PAK is present.
EAP AK (EAK)	160 bit	A key yielded from the EAP authentication. Always present

EAK lifetime		The lifetime of EAK, arrived from EAP.
AK	160 bit	The authentication key, calculated as f(PAK,EAK), if only EAP, AK=EAK.
AKID	64bits	Calculated according to the keys that contributed to AK: - If AK=f(EAK,PAK) then AKID=hash 64(EAP session-id | PAKID | BSID) - If AK=EAK then AKID=hash 64(EAP session-id | BSID) - If AK=PAK then AKID = PAKID
AK lifetime		This is the time this key is valid, it is calculated AK lifetime=MIN(PAK lifetime, EAK lifetime) – when this expires re-authentication is needed
H/OMAC_KEY_U	160/128 bit	The key which is used for signing UL management messages
H/OMAC_PN_U	32 bit	Used to avoid UL reply attack on management – when this expires re-authentication is needed
H/OMAC_KEY_D	160/128 bit	The key which is used for signing DL management messages
H/OMAC_PN_D	32 bit	Used to avoid rDL eply attack on management – when this expires re-authentication is needed
KEK	160 bit	Used to encrypt transport keys from the BS to the SS

7.2.2.4.2 GKEK context

The GKEK is the head of the group key hierarchy. There is a separate GKEK for each group (each GSA). This key is randomly generated by the BS and transferred to the SS encrypted with KEK.
It is used to encrypt group TEKs (GTEK) when broadcasting them to all SSs.
The GKEK context includes:

Parameter	Size	usage
GKEK	128 bit	Randomly generated by BS and transmitted to SS under KEK
GKEKID	64 bits	Arrives from BS with GKEK
GKEK lifetime		Arrives from BS with GKEK – when this expires a new GKEK should be obtained
H/OMAC_KEY_G	160/128 bit	The key which is used for signing group DL GTEK update messages, calculated by KDF(omac_PAD,GKEK)
H/OMAC_PN_G	32 bit	Used to avoid DL reply attack on management – – when this expires a new GKEK should be obtained

[Insert under the cryptographic algorithms section][DA1]

7.x.x.x.x Dot16KDF

The Dot16KDF algorithm is a CTR mode construction that may be used to derive an arbitrary amount of keying material from source keying material.

In the case that the HMAC/OMAC setting in the authentication policy bits is set to OMAC, the algorithm is defined as:

```
Dot16KDF(key, astring, keylength) is
{
        result = null;
        Kin = Truncate (key, 128);
        for (i = 0;i <= int((keylength-1)/128); i++)
        {
                result <= result | Truncate (OMAC(Kin, i | astring | keylength), 128);
        }
        return Truncate (result, keylength);
}
```

In the case that the HMAC/OMAC setting in the authentication policy bits is set to HMAC, the algorithm is defined as:

```
Dot16KDF(key, astring, keylength) is
{
        Kin = Truncate (key, 160);
        return Truncate (SHA-1(astring | Kin), keylength);
}
```

The key is a cryptographic key that is used by the underlying digest algorithm (SHA-1 or OMAC-AES). 'astring' is an octet string used to alter the output of the algorithm. 'keylength' is used to determine the length of key material to generate and is used in the digest input data to prevent extension attacks. Truncate(x,y) is the rightmost y bits of a value x only if y <= x.

[Change 11.9.3 as below to add in support for the AES Key Wrap algorithm]

11.9.3 TEK

Description: This attribute contains a quantity that is a TEK key, encrypted with a KEK derived from the AK.

Type	Length	Value (String)
8	8, 16 or 24	Encrypted TEK

When the TEK encryption algorithm identifier in the SA is 0x01, the length shall be 8 and the TEK shall be encrypted with 3DES in EDE mode according to the procedure defined in 7.5.2.1.

When the TEK encryption algorithm identifier in the SA is 0x03, the length shall be 16 and the TEK shall be encrypted with AES in ECB mode according to the procedure in 7.5.2.3

When the TEK encryption algorithm identifier in the SA is 0x04, the length shall be 24 and the TEK shall be encrypted with the AES Key Wrap algorithm according to the procedure in 7.5.2.4

[Insert an entry for AES Key Wrap into table 375a]

Table 375a—TEK encryption algorithm identifiers

Value	Description
0	Reserved
1	3-DES EDE with 128-bit key
2	RSA with 1024-bit key
3	ECB mode AES with 128-bit key
4	AES Key Wrap with 128 bit key
~~3~~5-255	Reserved

3.2 Remedy 2 – OMAC calculation correction

6.3.2.3.23 SS Basic Capability Request (SBC-REQ) message

[Replace the following section]

7.5.4 Calculation of OMAC-Digests

The calculation of the keyed hash in the OMAC-Digest attribute and the OMAC Tuple shall use the OMAC Algorithm with AES. The downlink authentication key OMAC_KEY_D shall be used for authenticating messages in the downlink direction. The uplink authentication key OMAC_KEY_U shall be used for authenticating messages in the uplink direction. Uplink and downlink message authentication keys are derived from the AK (see 7.5.4 below for details).

For authentication multicast messages (in the DL only) a OMAC_KEY_DG shell be used (one for each group), group authentication key is derived from GKEK

In the PKM version 2 protocol, The OMAC sequence number in the OMAC tuple shall be equal to the ~~48~~64 bit AKID of the AK from which the OMAC_KEY_x was derived. In the PKM version 1 protocol, The 4 least significant bits of the OMAC sequence number in the OMAC tuple shall be equal to the 4 bit AK sequence number and the 44 most significant bits shall be equal to 0.

The OMAC Packet Number (OMAC_PN_*) is a 4 byte sequential counter that is incremented in the context of UL messages by the MSS, and in the context of DL messages by the BS,. The BS will also maintain a separate OMAC_PN_* for multicast packets per each GSA and increment that counter in the context of each multicast packet from the group. For MAC messages that have no CID e.g. RNG-REG message, the OMAC_PN_* context will be the same as used on the basic CID.

The OMAC_PN counters are part of the OMAC security context and must be unique for each MAC management message with the OMAC tuple or digest.

In the receiving side, the PN comparison will be made on CID basis meaning – a packet is considered valid it it's PN is higher than the PN of last message in the same CID (or any other mechanism defined for H-ARQ OOO problem) – in order to avoid reply attack between different CIDs, the CID is part of the calculation of the OMAC.

The digest shall be calculated over a field consisting of the OMAC key sequence number followed by the OMAC_PN_* ~~the frame number~~ , expressed as an unsigned 32 bit number, followed by the 16 bit Connection ID on which the message is sent, followed by 16 bit of zero padding (for the header to be aligned with AES block size) and followed by the entire MAC management message with the exception of the OMAC-TLV~~Digest but including the OMAC Tuple attributes~~.

The least significant bits of the digest shall be truncated to yield a 64 bit length digest.

The OMAC key sequence number is identical to the KEYid it was derived from i.e AKID if derived from AK.

I.e.:

OMAC digest <= Truncate64(OMAC(OMAC_KEY_*, OMAC sequence number | OMAC_PN_* ~~| Frame number~~ | CID |16 bit zero padding | MAC_Management_Message ~~| OMAC_TLV_Attributes~~))

If the message is included in an MPDU that has no CID, e.g. A RNG-REQ message, the CID used shall take the value ~~0~~of the basic CID.

~~The frame number in which a message containing an OMAC tuple may be fragmented and so be transmitted in more than one frame number. In this case, the frame number used in the OMAC calculation shall take the value of the frame number of the frame in which the first fragment is transmitted.~~

[Replace the following section]

11.1.2.2 OMAC Tuple

This parameter contains the OMAC_PN_* and the OMAC Key Sequence Number concatenated with an OMAC-Digest itself used for message authentication. The OMAC_PN_* is stored in the 32 least significant bits of the tuple, followed with OMAC Key Sequence Number which is stored in the next ~~48~~64 bits of the OMAC Tuple. The OMAC-Tuple attribute format is shown in Table 347 and Table 348.

When included in a MAC management message, the OMAC tuple shall always be the final tuple in the message.

A message received, that contains an OMAC tuple, shall not be considered authentic if the length field of the tuple is not ~~17~~20, or if the locally computed value of the digest does not match the digest in the message.

Non authentic messages shall be discarded

Informative note: It would be appropriate for a MIB to increment an error count on receipt of a non authentic message, so that management can detect an active attack.

Table 345a—OMAC Tuple definition

Type	Length	Value	Scope
??	~~14~~20	See Table 346a	DSx-REQ, DSx-RSP, DSx-ACK, REG-REQ, REG-RSP, RES-CMD, DREG-CMD, TFTP-CPLT

Table 346a—OMAC Tuple definition

Field	Length	Note
OMAC Packet Number counter, OMAC_PN_*	32 bits	This context is different er UL, DL
OMAC Key sequence number	~~48~~64 bits	
OMAC Digest	64 bits	OMAC with AES 128

[Replace the following section]

11.9.32 OMAC Digest

Description: This attribute contains a packet number counter OMAC_PN_* incremented per packet on each direction and the Message Authentication Code used for message authentication. The OMAC algorithm is defined in draft SP 800-38B.

The OMAC digest includes

Type	Length	Value
40	~~8~~12	~~A 64 bit (8 byte) keyed OMAC~~See Table XXXX

Table XXXX—OMAC digest definition

Field	Length	Note
OMAC Packet Number counter, OMAC_PN_*	32 bits	This context is different er UL, DL
OMAC Digest	64 bits	OMAC with AES 128

3.3 Remedy 3 – 3 Way handshake and TEK exchange corrections

3.3.1 Summary of the solution:

Notation:

AK (Authentication Key)
This is the authentication key and can be created in three ways:
1) Just from PAK if only MSS authorization is done
2) Just from EAK if just EAP based user authentication is done
3) From PAK and EAK combined if both MSS authorization and user authentication are done.

AKID
This identifier is used to identify the shared AK, so depending upon how AK has been constructed it is also constructed based on three sources identified above.

RandomBS
A random value chosen by the BS (once per protocol run)

RandomSS
A random value chosen by the SS (once per protocol run)

KEK (Key Encryption Key)
This is a 128 bit key encryption key derived from the AK and is used to encrypt all TEK and GKEK exchanges between the MSS and the BS.

HMAC/OMAC
These keys are used for signing some of the management messages and are also derived from AK. OMAC keys are 128 bits long while HMAC keys are 160 bits long

TEK
These keys are randomly generated by the BS and transferred to the MSS encrypted by KEK and MACed (protected) by OMAC/HMAC. These are used to encrypt all the unicast traffic between MSS and BS.

GKEK
This key is randomly generated by the BS and transferred to the MSS encrypted by KEK and signed by OMAC/HMAC. This key is used to encrypt GTEK when it is sent from the BS as a multicast to MSSs that are members of a single multicast group.

GTEK
This key is randomly generated by the BS and transferred to all MSSs that are members of a single multicast group after encrypting it with GKEK. It can also be sent as a unicast to a single MSS, in which case it is encrypted with KEK. This key is used to encrypt multicast and broadcast traffic and is shared by all members of the group.

Protocol

1. MSS → BS Request:
    a. RandomSS
       This is a freshly generated random number generated by MSS that is used by MSS to ensure the freshness of the corresponding reply from BS.
    b. AKID
       This identifies the AK to the BS that is used for protecting this message.
    c. Security Capabilities

Describe requesting MSS's security capabilities. This includes the data encryption and data authentication algorithms the MSS supports.

d. OMAC/HMAC Digest
Message integrity code for this message.

2. BS → MSS Response:
   a. RandomSS
   This is a random number that was passed to the BS in the request by MSS and is returned by BS to MSS in the response.
   b. *Optional* RandomBS
   This is a freshly generated random number *optionally* generated by BS that is used by BS to ensure the freshness of the corresponding *optional* confirm message from MSS.
   c. AKID
   This identifies the AK to the BS that was used for protecting this message.
   d. SA_TEK_Update
   A TLV list each of which identifies the primary and static SAs, their SA identifiers (SAID) and additional properties of the SA (e.g., type, cryptographic suite) that the MSS is authorized to access. In case of HO, the details of any Dynamic SAs that the requesting MSS was authorized in the previous serving BS are also included.
   Additionally, in case of HO, for each active SA in previous serving BS, corresponding TEK, GTEK and GKEK parameters are also included. Thus, SA_TEK_Update provides a shorthand method for renewing active SAs used by the MSS in its previous serving BS. The TLVs specify SAID in the target BS that shall replace active SAID used in the previous serving BS and also "older" TEK-Parameters and "newer" TEK-Parameters relevant to the active SAIDs. The update may also include multicast/broadcast Group SAIDs (GSAIDs), associated GTEK-Parameters pairs and GKEK for the each GSA.
   In case of unicast SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of an SAID's TEK. This would include the TEK, the TEK's remaining key lifetime, its key sequence number and the cipher block chaining (CBC) initialization vector. The TEKs are encrypted with KEK.
   In case of broadcast or group SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of a GSAID's GTEK. This would include the GTEK, the GKEK[a2], the GTEK's remaining key lifetime, the GTEK's key sequence number, and the cipher block chaining (CBC) initialization vector. The type and length of the GTEK is equal to ones of the TEK. The GKEK should be identically shared within the same multicast group or the broadcast group. Contrary Key-Update Command, the GTEKs and GKEKs are encrypted with KEK because they are transmitted as a unicast here.
   Multiple iterations of these TLVs may occur suitable to re-creating and re-assigning all active SAs and their (G)TEK pairs for the MSS from its previous serving BS. If any of the Security Associations parameters change, then those Security Associations parameters encoding TLVs that have changed will be added.

   e. OMAC/HMAC Digest
   Message integrity code of this message.

3. *Optional* MSS → BS Confirm:
   This message is sent by MSS only if BS has included RandomBS in its Response.
   a. RandomBS
   This is a random number that was passed to the MSS in the response by BS and is returned by MSS to BS in the confirm.
   b. OMAC/HMAC Digest
   Message integrity code of this message.

3.3.2 Changes to 802.16e D5a text:

[6.3.2.3.9 Change Table 26a – PKM Message Codes]

13	EAP Transfer	PKM-REQ
~~14~~	~~EAP Establish-Key Request~~	~~PKM-RSP~~
~~15~~	~~EAP Establish-Key Reply~~	~~PKM-REQ~~
~~16~~	~~EAP Establish-Key Reject~~	~~PKM-REQ~~
~~17~~	~~EAP Establish-Key Confirm~~	~~PKM-RSP~~
18	Pre-Auth-Request	PKM-REQ
19	Pre-Auth-Reply	PKM-RSP
20	Pre-Auth-Reject	PKM-RSP
21	PKMv2 Auth Request	PKM-REQ
22	PKMv2 Auth Reply	PKM-RSP
XX	**SA-TEK-Request**	**PKM-REQ**
XY	**SA-TEK-Response**	**PKM-RSP**
XZ	**SA-TEK-Confirm**	**PKM-REQ**

Remove EAP-Establish-Key-Request, EAP-Establish-Key-Reply, EAP-Establish-Key-Reject and EAP-Establish-Key-Confirm

[Remove 6.3.2.3.9.12, 6.3.2.3.9.13, 6.3.2.3.9.14 and 6.3.2.3.9.15 and replace it with following: -]

6.3.2.3.9.12 SA-TEK-Request message

The MSS transmits the SA-TEK-Request message as a first step in the 3-way handshake. If this message is being generated during initial network entry, then this is a request for
SA-Descriptors identifying the primary and static SAs and GSAs the requesting SS is authorized to access and their particular properties (e.g., type, cryptographic suite).
If this message is being generated upon HO, then this is a request for establishment of TEKs, GTEKs and GKEKs at the MSS and renewal of active primary, static and dynamic SAs and associated SAIDs used by the MSS in its previous serving BS in the target BS.

Attribute	Contents
RandomSS	A freshly generated random number of 64 bits
AKID	This identifies the AK to the BS that was used for protecting this message.
Security-Capabilities	Describes requesting MSS's security capabilities
OMAC/HMAC	Message integrity code of this message

The Security-Capabilities attribute is a compound attribute describing the requesting MSS's security capabilities. This includes the data encryption and data authentication algorithms the MSS supports.

6.3.2.3.9.13 SA-TEK-Response message

The BS transmits the SA-TEK-Response message as a second step in the 3-way handshake.

Attribute	Contents
RandomSS	The random number received from MSS.
RandomBS	A freshly generated random number of 64 bits. This is optional.

AKID	This identifies the AK to the SS that was used for protecting this message.
SA_TEK_Update	A compound TLV list each of which specifies an SA identifier (SAID) and additional properties of the SA that the MSS is authorized to access. Additionally, in case of HO, for each active SA in previous serving BS, corresponding TEK, GTEK and GKEK parameters are also included.
OMAC/HMAC	Message integrity code of this message

SA_TEK_Update
A compound TLV list each of which identifies the primary and static SAs, their SA identifiers (SAID) and additional properties of the SA (e.g., type, cryptographic suite) that the MSS is authorized to access. In case of HO, the details of any Dynamic SAs that the requesting MSS was authorized in the previous serving BS are also included.
Additionally, in case of HO, for each active SA in previous serving BS, corresponding TEK, GTEK and GKEK parameters are also included. Thus, SA_TEK_Update provides a shorthand method for renewing active SAs used by the MSS in its previous serving BS. The TLVs specify SAID in the target BS that shall replace active SAID used in the previous serving BS and also "older" TEK-Parameters and "newer" TEK-Parameters relevant to the active SAIDs. The update may also include multicast/broadcast Group SAIDs (GSAIDs) and associated GTEK-Paramters pairs.
In case of unicast SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of an SAID's TEK. This would include the TEK, the TEK's remaining key lifetime, its key sequence number and the cipher block chaining (CBC) initialization vector. The TEKs are encrypted with KEK.
In case of group or multicast SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of a GSAID's GTEK. This would include the old and new GTEK parameter pairs, the GKEK, the GTEK's remaining key lifetime, the GTEK's key sequence number, and the cipher block chaining (CBC) initialization vector. The type and length of the GTEK is equal to ones of the TEK. The GKEK should be identically shared within the same multicast group or the broadcast group. The GTEKs and GKEKs are encrypted with KEK because they are transmitted as a unicast here.
Multiple iterations of these TLVs may occur suitable to re-creating and re-assigning all active SAs and their (G)TEK pairs for the MSS from its previous serving BS. If any of the Security Associations parameters change, then those Security Associations parameters encoding TLVs that have changed will be added.

6.3.2.3.9.12 SA-TEK-Confirm message

The MSS optionally transmits the SA-TEK-Confirm message in response to SA-TEK-Response message only if the SA-TEK-Response message contains RandomBS challenge.

Attribute	Contents
RandomBS	The random number received from BS
OMAC/HMAC	Message integrity code of this message

[Add 11.7.X]

11.7.X SA_TEK_Update

This field provides a translation table that allows an MSS to update its security associations and TEK pairs so that it may continue security service after a hand-over to a new serving BS.

Name	Type	Length (1 byte)	Value
SA_TEK_Update	?	variable	Compound

The following TLV values shall appear in each SA_TEK_Update TLV.

Name	Type	Length (1 byte)	Value
SA_TEK_Update Type	??	1	1 : TEK parameters for a SA 2 : GTEK parametes for a GSA 3 to 255: Reserved, Not used
New SAID	20.1	2	New SAID after hand-over to new BS
Old SAID	20.1	2	Old SAID before hand-over from old BS. In case of initial network entry, old SAID is same as new SAID
Old TEK/GTEK-Parameters	13/GTEK Type?	variable	"Older" generation of key parameters relevant to SAID. The Compound field contains the sub-attributes as defined in Table 370.
New TEK/GTEK –Parameters	13/GTEK Type?	variable	"Newer" generation of key parameters relevant to SAID. The Compound field contains the sub-attributes as defined in Table 370.
GKEK[a3]	GKEK Type?	16	GKEK for the corresponding GTEK pair if this TLV is for a GSA

[Add section 7.8.X]

7.8.X SA-TEK 3-way handshake

Depending on mutual authorization/EAP, AK can be derived in three different ways as documented in section XXX. Before the 3-way handshake begins, the BS and MSS shall both derive a shared AK, KEK and HMAC/OMAC as per section XXX.

The SA-TEK 3-way handshake sequence proceeds as follows:

1. The MSS shall send *SA-TEK-Request* to the BS after protecting it with the OMAC/HMAC. If the MSS does not receive *SA-TEK-Response* from the BS within SATEK*Timer*, it shall resend the request. The MSS may resend the *SA-TEK-Request* up to SATEK*RequestMaxResends* times. If the MSS reaches its maximum number of resends, it shall discard the AK and may do full re-authentication or decide to connect to another BS or take some other action. The message shall include RandomSS, AKID, SS's Security Capabilities and OMAC/HMAC.

2. Upon receipt of *SA-TEK-Request*, a BS shall confirm that the supplied AKID refers to an AK that it has available. If the AKID is unrecognized, the BS shall ignore the message. The BS shall verify the OMAC/HMAC. If the OMAC/HMAC is invalid, the BS shall ignore the message.

3. Upon successful validation of the *SA-TEK-Request*, the BS shall send *SA-TEK-Response* back to the MSS. The message shall include a compound TLV list each of which identifies the Primary and static SAs, their SA identifiers (SAID) and additional properties of the SA (e.g., type, cryptographic suite) that the MSS is authorized to access. In case of HO, the details of any Dynamic SAs that the requesting MSS was authorized in the previous serving BS are also included.
   Additionally, in case of HO, for each active SA in previous serving BS, corresponding TEK, GTEK and GKEK parameters are also included. Thus, SA_TEK_Update provides a shorthand method for renewing active SAs used by the MSS in its previous serving BS. The TLVs specify SAID in the target BS that shall replace active SAID used in

the previous serving BS and also "older" TEK-Parameters and "newer" TEK-Parameters relevant to the active SAIDs. The update may also include multicast/broadcast Group SAIDs (GSAIDs) and associated GTEK-Paramters pairs.
In case of unicast SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of an SAID's TEK. This would include the TEK, the TEK's remaining key lifetime, its key sequence number and the cipher block chaining (CBC) initialization vector. The TEKs are encrypted with KEK.
In case of group or multicast SAs, the TEK-Parameters attribute contains all of the keying material corresponding to a particular generation of a GSAID's GTEK. This would include the GTEK, the GKEK, the GTEK's remaining key lifetime, the GTEK's key sequence number, and the cipher block chaining (CBC) initialization vector. The type and length of the GTEK is equal to ones of the TEK. The GKEK should be identically shared within the same multicast group or the broadcast group. Contrary Key-Update Command, the GTEKs and GKEKs are encrypted with KEK because they are transmitted as a unicast here.
Multiple iterations of these TLVs may occur suitable to re-creating and re-assigning all active SAs and their (G)TEK pairs for the MSS from its previous serving BS. If any of the Security Associations parameters change, then those Security Associations parameters encoding TLVs that have changed will be added.
The OMAC/HMAC shall be the final attribute in the message's attribute list.

4. Upon receipt of *SA-TEK-Response*, an MSS shall verify the OMAC and ensure the presence of correct RandomSS. If the OMAC or RandomSS is invalid, the MSS shall ignore the message. Upon successful validation of the received *SA-TEK-Response*, the MSS shall install the received TEKs and associated parameters appropriately. Verification of OMAC is done as per section XXX. *If RandomBS was present in SA-TEK-Response, the MSS shall send SA-TEK-Confirm to the BS and an OMAC/HMAC digest.*

[Update Table 31-Key Request in section 6.3.2.3.9.5 as follows]

Attribute	Contents
~~Key Sequence Number~~	~~AK sequence number~~
RandomSS	This is a random number that was passed to the BS in the request by MSS and is returned by BS to MSS in the response.
SAID	Security Association ID
OMAC/HMAC-Digest	Message integrity code of this message

[Update Table 33-Key Reply in section 6.3.2.3.9.5 as follows]

Attribute	Contents
~~Key Sequence Number~~	~~AK sequence number~~
RandomSS	This is a random number that was passed to the BS in the key request by MSS and is returned by BS to MSS
SAID	Security Association ID
TEK-Parameters	"Older" generation of key parameters relevant to SAID
TEK-Parameters	"Newer" generation of key parameters relevant to SAID
OMAC/HMAC-Digest	Message integrity code of this message

[Add following two new MAC management messages in section 6.3.2.3]

6.3.2.3.XX GSA Key Request Message

This message is sent by MSS to query the GTEK parameters from BS for a GSA.

Attribute	Contents

RandomSS	This is a random number that was passed to the BS in the request by MSS and is returned by BS to MSS in the response.
GSAID	Global Security Association ID
OMAC/HMAC-Digest	Message integrity code of this message

6.3.2.3.XX GSA Key Reply Message [a4]

This message is sent by BS to send the GTEK parameters in response to a query from MSS.

Attribute	Contents
RandomSS	This is a random number that was passed to the BS in the request by MSS and is returned by BS to MSS in the response.
GSAID	Security Association ID
GTEK-Parameters	"Older" generation of key parameters relevant to SAID
GTEK-Parameters	"Newer" generation of key parameters relevant to SAID
GKEK	Key encryption key protected by KEK derived from shared AK
OMAC/HMAC-Digest	Message integrity code of this message

3.4 Remedy 4 – Pre-authentication support

[In IEEE P80216e_D5a modify table 26 – PKM message codes]

Table 26—PKM message codes

Code	PKM message type	MAC Management message name
0-2	*reserved*	—
3	SA Add	PKM-RSP
4	Auth Request	PKM-REQ
5	Auth Reply	PKM-RSP
6	Auth Reject	PKM-RSP
7	Key Request	PKM-REQ
8	Key Reply	PKM-RSP
9	Key Reject	PKM-RSP
10	Auth Invalid	PKM-RSP
11	TEK Invalid	PKM-RSP
12	Auth Info	PKM-REQ
13	EAP Transfer	PKM-REQ/PKM-RSP
14	EAP-Establish-Key Request	PKM-RSP
15	EAP-Establish-Key Reply	PKM-REQ
16	EAP-Establish-Key Reject	PKM-REQ
17	EAP-Establish-Key Confirm	PKM-RSP
~~18~~	~~Pre-Auth-Request~~	~~PKM-REQ~~
~~19~~	~~Pre-Auth-Reply~~	~~PKM-RSP~~
~~20~~	~~Pre-Auth-Reject~~	~~PKM-RSP~~
18-20	*reserved*	—
21	PKMv2 Auth-Request	PKM-REQ
22	PKMv2 Auth-Reply	PKM-RSP
23	Key Update Command	PKM-RSP

24	EAP Start	PKM-REQ
~~24~~25-255	*reserved*	—

[Delete sections '6.3.2.3.9.16 Pre-Auth-Request message', '6.3.2.3.9.17 Pre-Auth-Reply message' and '6.3.2.3.9.18 Pre-Auth-Reject message']

[Insert section 6.3.2.3.9.22]

6.3.2.3.9.22 EAP start

When an MSS has to initiate an authentication process with a BS, it sends an EAP start message.

Code: 24

This message has no attribute.

[insert text and tables as follows]

6.3.2.3.59 Privacy key management – remote (PKMR) messages (PKMR-REQ/PKMR-RSP)

PKMR employs two MAC message types: PKMR Request (PKMR-REQ) and PKMR Response (PKMR-RSP), as described in Table xx1.

Table xx1—PKMR MAC messages

Type Value	Message Name	Message Description
??	PKMR-REQ	Privacy Key Management – Remote Request [MSS→ BS]
??	PKMR-RSP	Privacy Key Management – Remote Response [BS→ MSS]

These MAC management message types distinguish between PKMR requests (SS–to–BS) and PKMR responses (BS–to–SS). Each message encapsulates one PKMR message in the Management Message Payload.

PKMR protocol messages transmitted from the SS to the BS (PKMR-REQ) shall use the form shown in Table xx2. They are transmitted on the MSSs Primary Management Connection.

Table xx2—PKMR request (PKMR-REQ) message format

Syntax	Size	Notes
PKMR-REQ message format {		
Management Message Type = ??	8 bits	
Target BSID	24 bits	Least significant 24 bits of the target BS ID
Code	8 bits	
PKMR identifier	8 bits	
TLV Encoded Attributes	*variable*	TLV specific
OMAC/HMAC Tuple	23/16	According to agreement in capabilities phase. This signature is calculated from keys used with the serving BS and will be verified by the serving BS
}		

PKMR protocol messages transmitted from the BS to the SS (PKMR-RSP) shall use the form shown in Table xx3. They are transmitted on the SSs Primary Management Connection.

Table xx3—PKMR response (PKMR-RSP) message format

Syntax	Size	Notes
PKMR-REQ message format {		
Management Message Type = ??	8 bits	
Source BSID	24 bits	Least significant 24 bits of the source BS ID
Code	8 bits	
PKMR identifier	8 bits	
TLV Encoded Attributes	*variable*	TLV specific
OMAC/HMAC Tuple	128 or 184	According to agreement in capabilities phase. **This signature is for the serving BS and not the target BS**
}		

The parameters shall be as follows:

Code

The Code is one byte and identifies the type of PKMR packet. When a packet is received with an invalid Code, it shall be silently discarded. The code values are defined in Table xx4.

PKM Identifier

The Identifier field is one byte. An SS uses the identifier to match a BS response to the SS's requests.

The SS shall increment (modulo 256) the Identifier field whenever it issues a new PKMR message. A "new" message is an PKMR-REQ that is not a retransmission being sent in response to a Timeout event. For retransmissions, the Identifier field shall remain unchanged.

The Identifier field in a BS's PKMR-RSP message shall match the Identifier field of the PKMR-REQ message the BS is responding to.

On reception of a PKMR-RSP message, the SS associates the message with a particular state machine (EAP stack for EAP messages).

Attributes

PKMR attributes carry the specific authentication, authorization, and key management data exchanged between client and server. Each PKMR packet type has its own set of required and optional attributes. Unless explicitly stated, there are no requirements on the ordering of attributes within a PKMR message. The end of the list of attributes is indicated by the LEN field of the MAC PDU header.

Table xx4— PKMR message codes

Code	PKMR message types	MAC management message name
13	EAP transfer	PKMR-REQ/PKMR-RSP
24	EAP start	PKMR-REQ

Formats for each of the PKMR messages are described in the following subclauses. The descriptions list the PKMR attributes contained within each PKMR message type. The attributes themselves are described in 11.9. Unknown attributes shall be ignored on receipt and skipped over while scanning for recognized attributes.
The BS shall silently discard all requests that do not contain ALL required attributes.

6.3.2.3.59.1 EAP Transfer message

When an MSS has an EAP message received from an EAP method for transmission to a remote BS or when a remote BS has an EAP message received from an EAP method for transmission to the MSS, it encapsulates it in an EAP Transfer message.

Code: 13

Attributes are shown in Table xx5.

Table xx5 – EAP transfer attributes

Attribute	Contents
EAP protocol	Contains the EAP authentication data, not interpreted in the MAC

The EAP Payload field carries data in the format described in section 4 of RFC2284bis

6.3.2.3.59.2 EAP Start message

When an MSS has to initiate an authentication process with a BS, it sends an EAP start message.

Code: 24

This message has no attribute.

3.5 Remedy 5 – HO optimization support

3.5.1 Summary of the solution:

This contribution defines one capability bit, three configuration bits, and a key-zone information field. The serving BS sends these pieces of information to the MSS regarding a potential target BS to which MSS may handoff.
Also defined here some messages and decision flow that allow the MSS, based on the information he received, to decide what to do in order to obtain authentication with target BS, in advance, while maintaining high level of security.

Authentication
Obtaining authentication between an MSS and a BS is defined as sharing a unique AK (and its context) between them.
According to the key-hierarchy as defined in this contribution, the source for AK after HO is only EAP authentication which means AK=EAK which is derived from PMK.
For the purpose of this contribution, the phraseology will be that AK is derived from PMK instead of saying AK equals EAK which is derived from PMK.

Authentication caching
Deriving AK from PMK per BS-SS tuple is allowed only once.
This is because when AK is derived in the first time, a fresh context is created to support the usage of AK.
This context contains IDs, Counters and lifetimes of its members.
If AK will be derived again from the same PMK and a fresh context will be created again, the system will not be secure because it will be vulnerable to reply attacks.
In order to avoid this situations, both entities (MSS and BS) must cache the context for as long as the PMK which the AK was derived from is valid.

This is to be able to continue using the context of AK from the point it was stopped in the scenario that the MSS HO to a BS it has already been connected to and the PMK from which AK was derived last time is still valid.
In case one of the entities losses the AK context from any reason, it must invalidate the related PMK to ensure context reuse is not possible.

Key-Zone
A key-zone is defined as the deployment scenario in which multiple BSs derive their unique AKs for an MSS from a single PMK associated with that MSS. One way to use a shared PMK and maintain security is by putting it in a central server that populate the BSs with their unique AK. The network architecture to support key-zone is out of scope here.
An important property of key-zone is that an MSS needs to pre-authenticate only one BS in a key-zone in order to be pre-authenticated with all of them. A network can have multiple key-zones. A BS always belongs to a single key-zone which implies that for an MSS, a BS always has a single PMK source for AK.

Capability Bit: Pre-Authentication Support (1-bit)
This bit informs the MSS if the target BS has the pre-authentication capability.
Since the pre-authentication is base on tunneling messages from BS to BS and tunneling may be possible even if there is no "control" path between the BSs, the default state of this bit is set.
The only way this bit may be clear is if there is positive information that the target BS does not support pre-authentication.

Configuration Bit: PMKvalid
This bit informs the MSS if the target BS and current serving BS share a valid PMK. If this bit is Set then serving and target BS share same PMK for the MSS and that MSS may derive AK for the target BS from its current PMK or use an already derived AK+context if exists.
This bit can also serve as a notification to the MSS that a BS in the same key-zone lost the AK context for the MSS and that the MSS will need to re-authenticate and generate a fresh PMK.

Configuration Bit: authentication Context Valid
This bit informs the MSS if a particular BS in a different key-zone which the MSS thinks he has a shred context with (PMK if was not connected to and AK if was).
It is used by the MSS before HO to a TBS in a different key-zone to know if he can use the context he think he has for the BS or if he need to do pre-authentication.

Configuration Bit: Skip TEK exchange
This bit informs the MSS that it may reuse the existing TEKs from the current serving BS for traffic exchange with the target BS for the duration TEKs are valid.

Information relevancy
The information regarding HO as defined above can be separated into 2 groups according to its relevancy:
The key-zone and the pre-authentication capability are relevant to all MSSs connected to the BS and therefore will be transmitted in broadcast messages:

- The key-zone will be transmitted in the DCD so it will be also included in the NBR-ADV.
- The per-authentication capability will be transmitted in the NBR-ADV.

The configuration may have different values for each MSS and therefore will be send in unicast messages, the key-zone and pre-authentication capability will also be transmitted in the same unicast messages for the case where the MSS needs the information but didn't have the chance to receive the broadcast yet.
The messages are:

- MOB-BSHO-REQ
- MOB_BSHO-RSP
- MOB-BSHO-INF
- RNG_RSP (in target BS and only the configuration bits).

Using the information by the MSS

The MSS should maintain a table of PMK->key-zone mapping for each PMK he has.

When the MSS decide it need to prepare for HO to a target BS (the way it does it is out of scope for this contribution) he examines the target BS key-zone and its own key-zone:

- If both are equal, the SS can assume he can use the AK that is derived from his current PMK and bind to the target-BSid.
  If he wishes to validate this he should send HO-QRY to the BS or initiate HO by sending SS-HO-REQ, in the answer message for one of these messages he will get the configuration bits relevant to him and will be able to see if the PMK valid bit is on.
  If it is on, he can HO and use the derived AK, if it is off it means that the target BS do not allow him to do it and he need to do full authentication after HO.
  It may choose to try re-authenticating to his serving BS in case the problem with the target BS is temporal and renewing PMK for the entire key-zone may solve it.
- If they are in different key-zones the MSS should check if he has an AK cached for this BS or if he has PMK for this key-zone (in this order).
  - If both are missing he may do pre-authentication with the target BS if the pre-authentication capability bit is set.
    It may use the INF or BS-RSP messages to validate the authenticationCOntextVALID bit is on from the BS side.
    If so he can HO and derive the AK from the PMK arrive by pre-authentication.
  - If one of them appears, the MSS should check the authenticationCOntextVALID bit to see if it is also exists in the BS side.
    If exist he can use the AK he cached after HO if not he may pre-authenticate to this BS to renew PMK.

After actual HO, the BS will get RNG-RSP signed with OMAC/HMAC using the AK he derived before the HO.

If he can't verify the MAC, he should discard this message and perform full network-entry.

If the MAC is verified, he needs to look at 1 configuration bit – the skipTEK, if it is set he should continue using his old TEK keys and context. If it is unset he should ask for new TEK as described in 3-way-handsahke part of this contribution .

The skipTEK bit appears also in the HO messages and the MSS can use it to assume what he will need to do after HO but the final decision is as defined in the RNG-RSP and the MSS must follow it.

Context loss behavior

As described above, the caching of AK context is crucial for security as long as PMK is valid between an MSS and a key-zone.

In the case the context is lost by one entity, this entity must invalidate PMK so there will be no possibility that this AK will be re-derived with fresh context.

There are 4 options for context lost and these are the ways to deal with them:

- The BS and SS belong to the same key-zone, the SS losses the context – the SS must re-authenticate thus renewing PMK for all BSs in the key-zone including his.
- The BS and SS belong to the same key-zone, the BS losses the context – the BS must invalidate PMK for all BSs in the key-zone, the serving BS will notice that PMK is invalid and initiate a re-authentication with the MSS.
- The BS and SS belong to the different key-zone, the SS losses the context – the SS just need to erase the entry of these PMK from his PMK->key-zone mapping (and all AKs derived from it) thus when wanting to HO to this zone will notice he has no PMK and pre-authenticate.
- The BS and SS belong to the different key-zone, the BS losses the context – the BS just have to invalidate the PMK of this MSS, when the MSS will try to HO to this key-zone, the authenticationValidBit will be clear and the MSS will pre-authenticrte.

PKM optimization bit in HO optimization
This bit will change his meaning and he will tell if all the HO optimization as described here is relevant or not:

- If this bit is set – it means all configuration bits appear and the mechanism should be used.
- If this bit is unset – it means no optimization of security supported, need to do full PKM phase in every HO.

3.5.2 Changes to 802.16e D5a text headlines:

Define key-zone field.
Define pre-authentication capability bit.
Define 3 configuration bits field.

Add key-zone field to DCD.
Add capability bit to NBR-ADV.
Add configuration bits, key-zone and capability to MOB-BSHO-REQ/RSP
Add configuration bits to RNG-RSP

Define MOB-SSHO-QRY/MOB-BSHO-INF messages.

Add chapter describing solution.
Add description of field usage by SS
Add algorithm for context loss situation.

3.6 Remedy 6 – Mutual Authorization support

Update 6.3.2.3.9.19 PKMv2 Authorization Request (Auth Request) message

Code: 21
Sent by the SS to the BS as the first frame to ask for authorization.

Attributes are shown in Table 37i

Table xx

Attribute	Contents
SS_RANDOM	A 64 bit random number generated in the SS
SS Certificate	Contains the SS's X.509 user certificates
Security ~~Capabilities~~ suites	Describes requesting SS's security capabilities (Optional, only if there is no EAP phase afterwards)
~~AAID~~ SAID	SS's primary SAID equal to the Basic CID

The SS-certificate attribute contains an X.509 SS certificate (See 7.6) issued by the SS's manufacturer. The SS's X.509 certificate and Security Capabilities attribute is as defined 6.3.2.3.9.2

6.3.2.3.9.20 Auth-Reply message

Sent by the BS to a client MSS in response to an Authorization Request, the Authorization Reply message contains a PAK, the key's lifetime, the key's sequence number, and a list of SA-Descriptors identifying the Primary and Static SAs the requesting MSS is authorized to access and their particular properties (e.g., type, cryptographic suite). The PAK shall be encrypted with the MSS's public key. The SA-Descriptor list shall include a descriptor for the ~~Basic CID~~ primary SA reported to the BS in the corresponding Auth-Request. The SS_Random number is returned from the auth-req message, along with a random number supplied by the BS, thus enabling assurance of key liveness.

Code: 22

Attributes are shown in Table 37j.

Table 37j

Attribute	Contents
MSS_RANDOM	A 64 bit random number generated in the SS
BS_RANDOM	A 64 bit random number generated in the BS
~~MSS_Certificate~~	~~Contains the MSS's X.509 user certificate~~
Encrypted pre-PAK	RSA-OAEP-Encrypt(PubKey(MSS), pre-PAK | Id(MSS)
PAK Lifetime	PAK aging timer
PAK Sequence Number	64bit PAK Sequence number
~~AAID/SAID~~ (one or more) SA-Descriptor(s)	The primary SA and zero or more static SAs. Each compound SA-Descriptor attribute specifies an SAID and additional properties of the SA (optional, only if there is no EAP phase afterwards)
BS Certificate	Contains the BS's X.509 certificate
SigBS	An RSA signature over all other attributes in the message

6.3.2.3.9.XX PKMv2 Authorization Acknowledgement (Auth Ack) message

Code: X+2

Sent by the SS to BS as an acknowledgement of successful BS Authorization.

Table xx+2

Attribute	Contents
BS_RANDOM	A 64 bit random number generated in the BS
SS_MAC_Address	Contains the SS's MAC address
OMAC Tuple	OMAC calculated using OMAC key derived from PAK.

7.8.2.2 MSS and BS mutual authorization and AK exchange overview

The BS mutual authorization can take place in 2 cases: The first case is if this is the only mechanism used for authorization and in this case it will be performed upon any network (re)entry.
The second case is when it followed by EAP authentication: in this case the mutual authorization is done only for initial NW-E and only EAP is done in case authentication is needed in re-entry.

MSS mutual authorization, controlled by the PKMv2 Authorization state machine, is the process of
a) The BS authenticating a client MSS's identity
b) The MSS authenticating the BS's identity
c) The BS providing the ~~authenticated~~ Authorized MSS with an AK, from which a key encryption key (KEK) and message authentication keys ~~are derived~~ can be derived (If EAP is also done the AK and sub-keys is derived from both key sources)
d) The BS providing the authenticated MSS with the identities (i.e., the SAIDs) and properties of primary and static SAs the MSS is authorized to obtain keying information for.
After achieving initial authorization and in case this is the only authorization method used, the MSS periodically seeks reauthorization with the BS; reauthorization
is also managed by the MSS's PKMv2 Authorization state machine. An MSS must maintain its authorization status with the BS in order to be able to refresh aging TEKs and GTEKs. TEK state machines manage the refreshing of TEKs.
The MSS sends an Authorization Request message to its BS immediately after sending the Authentication Information message. This is a request for an AK, as well as for the SAIDs identifying any Static Security SAs the MSS is authorized to participate in. The Authorization Request includes
a) a manufacturer-issued X.509 certificate
b) a description of the cryptographic algorithms the requesting MSS supports; an MSS's cryptographic ~~capabilities~~ suites are presented to the BS as a list of cryptographic suite identifiers, each indicating a particular pairing of packet data encryption and packet data authentication algorithms the MSS supports
c) the MSS's primary Said (equals Basic CID). The Basic CID is the first static CID the BS assigns to an MSS during initial ranging~~— the primary SAID is equal to the Basic CID.~~
In response to an Authorization Request message, a BS validates the requesting MSS's identity, determines the encryption algorithm and protocol support it shares with the MSS, activates an PAK for the MSS, encrypts it with the MSS's public key, and sends it back to the MSS in an Authorization Reply message. Randomnumbers are included in the exchange to ensure liveness.
In response to an PKMv2 Authorization reply message, a SS shall validates the replying BS's identity by X.509 digital certificate, and authenticating the message by running hash function defined in RSA hash function with BS's private key. SS may acknowledge Authorization Reply by sending Authorization Acknowledgement or Authorization Reject
The PKMv2 authorization acknowledge includes:
a) a 64 bits random number received in auth reply
b) SS MAC address
c) OMAC Digest (used PAK for OMAC key derivation and 0 as PN)
The BS shall determine successful mutual authorization upon receiving PKMv2 Authorization acknowledgement message. If the PKMv2 Auth Ack, Auth Reject, or further PKM message such as EAP or KEY Request message is not received during certain time skew, BS may remove authorization state according to the operator policy

An, MSS which this is its only authorization method ,shall periodically refresh its PAK by reissuing an Authorization Request to the BS. Reauthorization is identical to authorization. To avoid service interruptions during reauthorization, successive generations of the MSS's AKs have overlapping lifetimes. Both MSS and BS shall be able to support up to two simultaneously active AKs during these transition periods. The operation of the Authorization state machine's
Authorization Request scheduling algorithm, combined with the BS's regimen for updating and using a client MSS's AKs (see 7.4), ensures that the MSS can refresh TEK keying information without interruption
over the course of the MSS's reauthorization periods.

[Modify Table 368a as follows:]

Table 368a—PKM attribute types

Type	PKM Attribute
~~31~~	~~AA Descriptor~~
~~32~~	~~AA Type~~

3.7 Remedy 7 – Authorization Policy Support Negotiation

[In IEEE P80216e_D5a p411, line 1, change text and table as follows]

11.8.4 Authorization policy support

This field indicates authorization policy used by the MSS and BS to negotiate and synchronize. A bit value of 0 indicates "not supported" while 1 indicates "supported."

Type	Length	Value	Scope
5.25	1	Bit #0: RSA (if PKM version 1, unidirectional authorization, in PKM version 2, mutual authorization) Bit #1: EAP (if PKM version 1 can not be set with RSA bit) ~~Bit #2: PHY frame number in authentication tuple~~ ~~Bit #3: Mutual Auth/Unidirectional Auth~~ Bit #2: OMAC supported (if set to 0, HMAC is the default) Bit #3-7: R*eserved.* Set to 0	SBC-REQ SBC-RSP