Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**	
Title	**Privacy key management for BSs and BSISs in 802.16 LE Systems**	
Date Submitted	**2005-09-09**	
Source(s)	Hung-Lin Chou, Chi-Chen Lee, Industrial Technology Research Institute, Computer and Communications Research Labs, Taiwan Bldg. 11, 195 Sec. 4, Chung Hsing Rd. Chutung, HsinChu, Taiwan 310, R.O.C.	Voice: +886-3-5912042 Fax: +886-3-5829733 mailto: hunglinchou@itri.org.tw
Re:	Call for Contributions, IEEE 802.16h Task Group on License-Exempt Coexistence, IEEE 802.16h-05/014, 2005/06/09	
Abstract	Propose the PKM protocol for intercommunications in 802.16 LE.	
Purpose	Information.	
Notice	This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.	
Release	The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.	
Patent Policy and Procedures	The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.	

Privacy Key Management for BSs and BSISs in 802.16 LE Systems

Hung-Lin Chou, Chi-Chen Lee
Computer & Communications Research Labs, ITRI, Taiwan

1. Introduction

This document proposes an enhanced network architecture which is distributed and more flexible. Besides, the related Privacy Key Management protocol for 802.16 LE systems is also introduced.

2. Background

In session#37, the architecture proposed in [1] was accepted. However, the accepted architecture requires a regional centralized RADIUS server and BSIS(in session #38, the CIS(Coexistence Identification Server) is renamed to BSIS(Base Station Identification Server)) which may lack for flexibility and scalability. Moreover, it is more reasonable that each operator has its own RADIUS server for authentication. This proposal intends to reduce the key management complexity of the RADIUS server and the maintenance overhead of BSIS. In the enhanced architecture, only the global RADIUS server (here may be more than one global server) called “root” RADIUS server remains and the BSISs will be distributed. All RADIUS servers and BSISs of the 802.16 LE operators shall register IP addresses of RADIUS servers and BSISs as well as the country code of the operator to the root RADIUS server(s). An 802.16 LE system learns other existing 802.16 LE systems by querying the root RADIUS server(s) using its own country code and neighboring country code.
A new re-key mechanism is proposed, as the previous re-key procedures rely on Radius-Server to generate security blocks and Security Parameters Index (SPIs) (a field of ESP header which identifies the security parameters in combination with IP address) and Keys for the BSs/BSISs. The loading of SPIs/Keys update of Radius-Server will be an issue as the number of BSs increases. For multiple Radius-Servers environment, the new PKM protocol provides an easier way to regenerate the session-key that secures the communications between BSs/BSISs based on the Master-Key, which is for generating session-key. The original IAPP-based solution relies on Radius Server to keep security information parameters and BSs mapping (ex: SPI、Security Association and Supporting Transform/Authentication Algorithm…etc). While BSs need to re-key or to create a new SPI/SA, Radius Server must involve and handle message exchange between BSs/BSIS. The proposed mechanism resolves the issue of SPIs/Keys mapping in multiple Radius-Servers environment by avoid the SPI/SA mapping, i.e. the Radius Server will not involve the re-key procedures.

In session#38, we discuss the different security issues of 802.16e and 802.16h. For 802.16e, the encrypted data packets just transmit between SS and BS in air-interface, and the authentication/authorization/accounting procedures adopt EAP (Extensible Authentication Protocol). For 802.16h, it needs different secure thinking for packet passing through each network equipment (ex: routers/firewalls). IPSec is a common secure connection solution for IP-network and also applied to IPv4 and IPv6 environment. General firewalls also know how to check the header of IPSec packet (AH or ESP header) and have the filtering rules to decide whether the IPSec packets could be allowed to pass through or not.

Acronyms

BSIS	—	Base Station Identification Server
PKM	—	Private Key Management
IPsec	—	Internet Protocol Security
ESP	—	IP Encapsulating Security Payload
AH	—	Authentication Header

3. Suggested remedy

(1) Proposed enhancement of general architecture for inter-network communication

[insert the following section into 2.1.2.1 Architecture]

Considering the IP network firewalls and different filtering rules, we should find a common security solution to make BSs/BSISs data connection transparent under almost common network management cases. IPSec is used to IPv4 and also included in IPv6 for the IP-Layer security solution. And all BSs/BSISs don't just reside in the same network environment. The data connections should go through some routers/firewalls and need to follow a common security rules.

Figure 1 shows the BSs/BSISs connections encrypted in IPSec. Based on IPSec, all data connections between BSs/BSISs could pass through firewalls and routers unless some firewalls block IPSec connections.

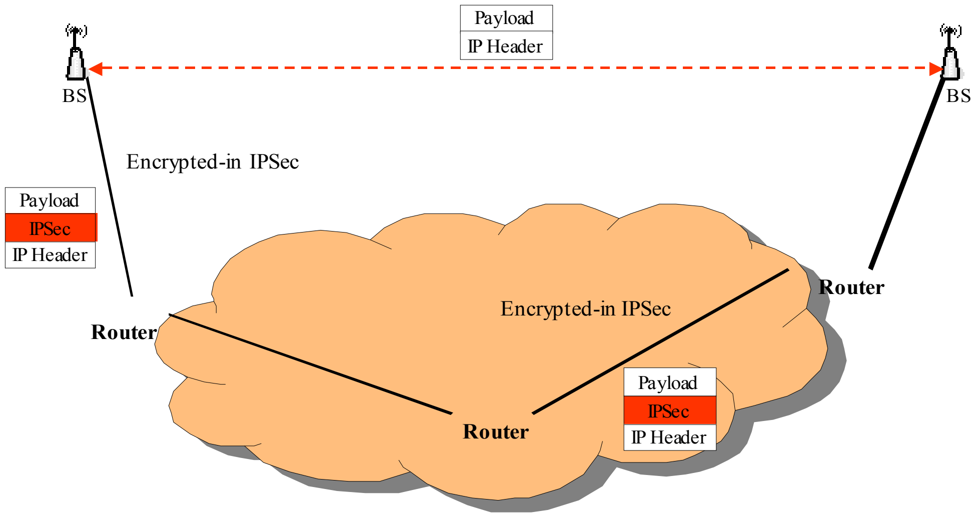


Figure 1 BSs/BSISs connection encrypted in IPSec

Figure 2 demonstrates the IEEE 802.16 LE inter-network communication architecture under multi-Operators with multi-Radius Servers.

If BS-1 wants to communicate with BS-2, it must get BS-2's Country's Code, Operator ID and BSID from local BSIS first. And then work as the following steps

(2) BS-1 send Radius-Access-Request frame with BS-2's Country's Code, Operator ID and BSID to Radius-Server
(3) Radius-Server will act as Radius-Proxy and transfer this Radius-Access-Request to the target Radius-Server
(4) Target Radius-Server will response Radius-Access-Accept with Pairwise-Master-Key and PMK-index for BS-1 and BS-2
(5) BS-1 will receive Radius-Access-Accept from its local Radius-Server and get the Pairwise-Master-Key and PMK-index

(6) BS-1 will act as a PKM-initiator to send Session-Key-Start to BS-2

(7) BS-2 will calculate the ESP-Key-Stuffs with Master Key and response Session-Key-Request to BS-1

(8) BS-1 will also calculate the ESP-Key-Stuffs with Master Key to verify Key-Signature and response Session-Key-Response to BS-2

(9) BS-2 will verify Key-Signature and response Session-Key-Accept to BS-1

(10)After the above procedures, BS-1 and BS-2 could communicate in IPSec with the ESP-Key-Stuffs generated dynamically

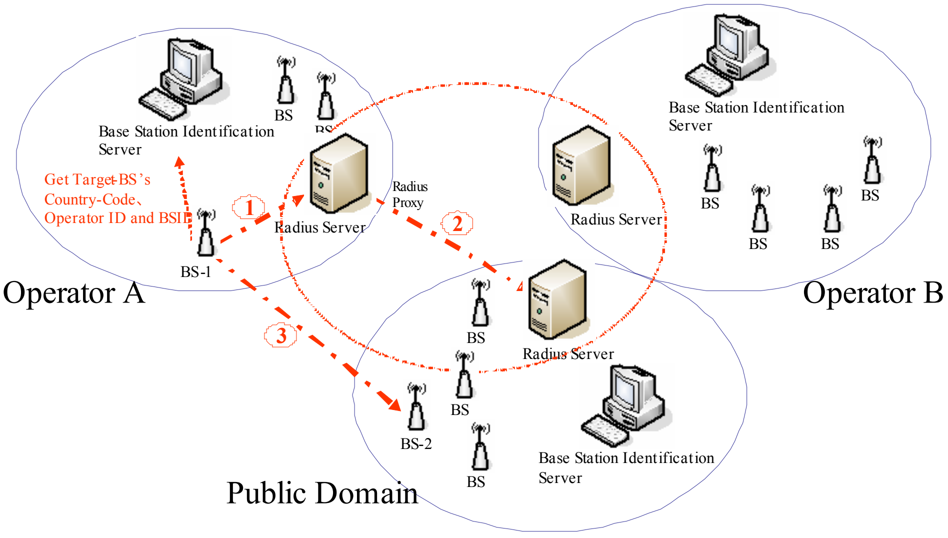

Base Station Identification Server
BS
BS
Get Target-BS's Country-Code、Operator ID and BSID
BS-1
1
Radius Server
Radius Proxy
2
Operator A
3
Base Station Identification Server
BS
BS
BS
BS
Radius Server
Operator B
BS
Radius Server
BS
BS-2
BS
Base Station Identification Server
Public Domain

Figure 2 Network Architecture under multi-Operators with multi-Radius Servers

The following figure shows the IEEE 802.16 LE Network Hierarchy for Radius-Servers to find another Radius Servers via the Root-Radius-Server by the Country Code.

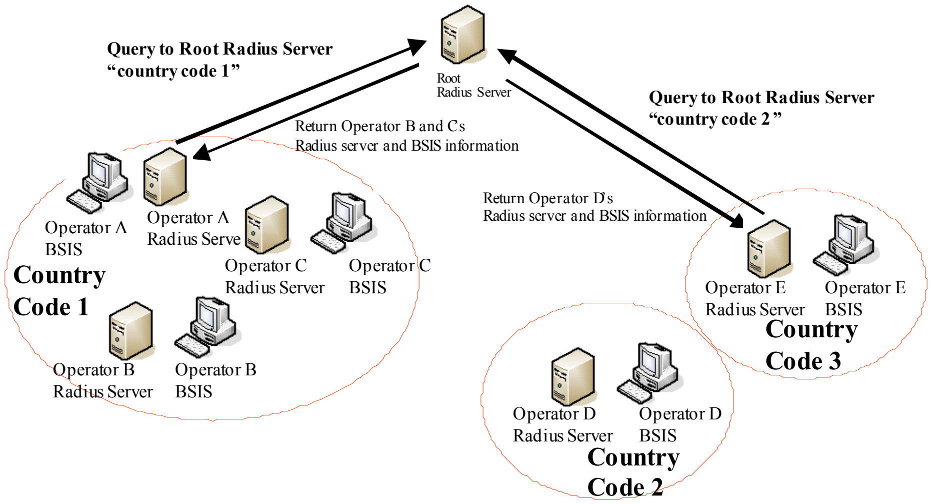


Figure 3 Network Hierarchy for Radius-Servers

For the IEEE 802.16 LE, we want it to work with multi-Radius-Servers, but how to find each Radius-Server near local Radius-Server would be a critical issue. The Root-Radius-Server will place a Key-Role for each Radius-Server to find the Radius-Servers in the near countries by Country-Codes. Based on this mechanism, each Radius-Server need to keep shared-key with the Root-Radius-Server and use the Radius-Access-Request frame to request the target Country-Code's Radius-Servers information. The Root-Radius-Server will response those information in Radius-Access-Accept frame. The response information will include Operators' Radius-Servers and BSISs information of the target Country-Code.

The following figure shows the each connection of BSs/BSISs will be encrypted in individual Session-Key.

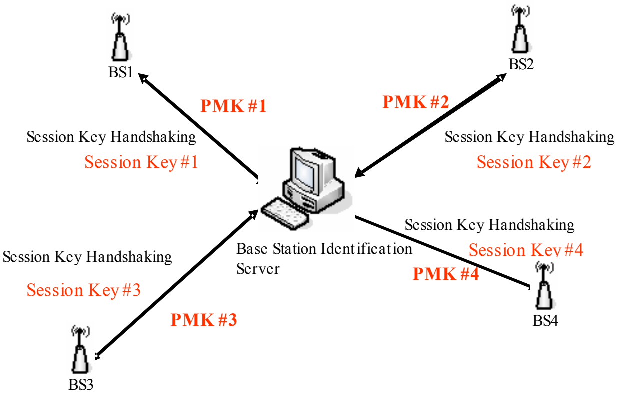


Figure 4 Individual Session-Key

For the BSs/BSISs, each connection with different BSs/BSISs will use individual Session-Key. Those Session Keys would be generated from PKM-Handshaking with Pairwise-Master-Keys of target BSs/BSISs. The re-key procedures also don't need Radius-Servers and just use Pairwise-Master-Keys of target BSs/BSISs.

(2) Proposed enhancement of RADIUS protocol usage

[replace section 3.2.4.2 with the following]

3.2.4.2 RADIUS Protocol usage

For future interoperability consideration, similar mechanisms in [2] are maintained. Secure exchange of 802.16 LE signaling information can be achieved after successful procedures of the RADIUS protocol. To include RADIUS support, the RADIUS server and the BS/BSIS RADIUS client must be configured with the shared secret and with each other's IP address. Each BS/BSIS acts as a RADIUS client and has its own shared-secret with the RADIUS server. The shared secret may be different from that of any other BS/BSIS.

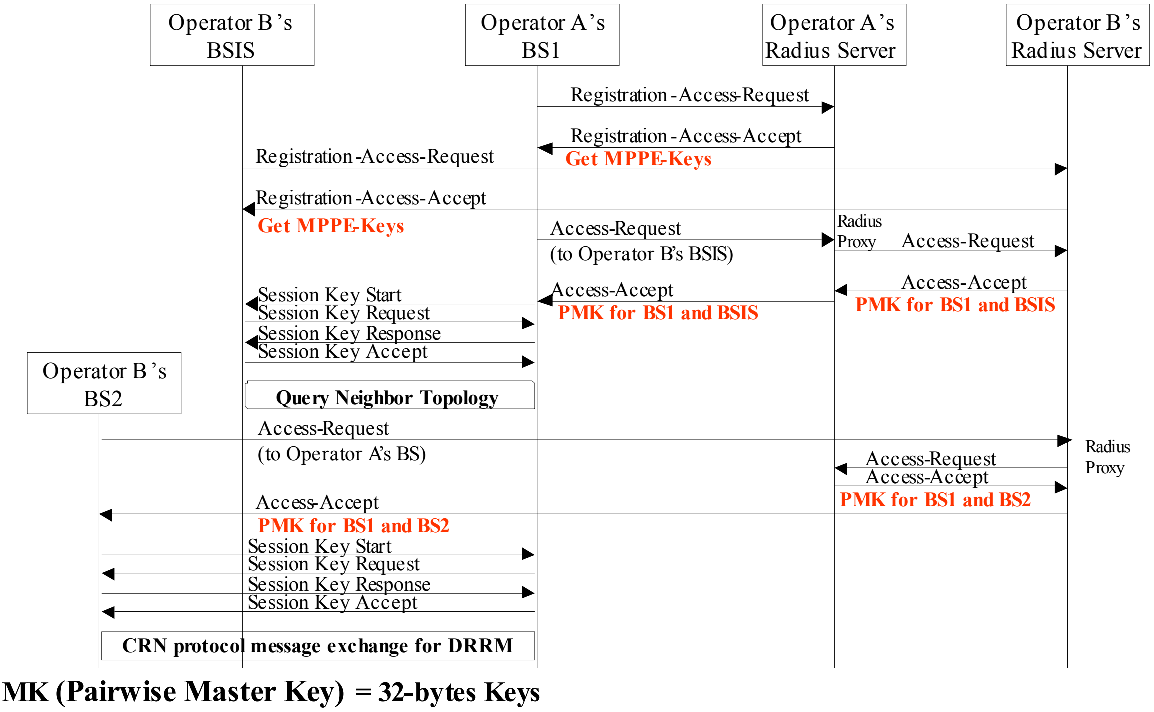


Figure 5 RADIUS protocol example

Figure 5 shows the RADIUS protocol message exchange sequence. At starting up, each BS or BSIS must send a Radius-BS/BSIS-Registration-Access-Request (shown in table 1) to the RADIUS server for authentication purpose and leave the address mapping (BSID to IP) information in the server. At this time, the RADIUS server will retain the following information of registered BS or BSIS:

(a) Wireless medium address of BS (BSID) or medium address of BSIS,
(b) RADIUS BSID Secret at least 160 bits in length,
(c) MPPE-Keys in Radius-BS/BSIS-Registration-Access-Request/Accept Procedures
(d) IP address or DNS name,
(e) Cipher suites supported by the BS or BSIS for the protection of Coexistence Protocol communications, and Pairwise-Master-Key for BS or BSIS to establish Session-Key-Handshaking procedures

Same as [2], Microsoft Point-to-Point Encryption (MPPE) (RFC 2548:1999) key is introduced. The MS-

MPPE-Send-Key, which could be got in the Radius-BS/BSIS-Registration-Access-Accept message (shown in table 2), is used for encrypting the security blocks in the Radius-BS/BSIS-Access-accept message. A registration access reject message may be issued due to a BS not supporting the ESP Transform or ESP Authentication algorithm selected for use in securing the following intercommunication, or for other RADIUS configuration reasons not discussed here.

Once a BS wants to get the knowledge of neighbor topology, it must first send Radius-BS/BSIS-Access-Request message (shown in table 4) to the RADIUS server in order to acquire the regional BSIS's IP address. The wireless medium addresses of regional BSIS, similar to BSID, well known by all BSs supporting LE operation, is sent in the Radius-BS/BSIS-Access-Request message to the RADIUS server for looking up IP address of the BSIS. Upon receiving the request message, the RADIUS server will respond with a Radius-BS/BSIS-Access-Accept message (shown in table 5) if the BS is a valid member which is allowed to perform inter-communication. The Radius-BS/BSIS-Access-Accept message would contain Originated-BS-Security-Block(for BS encrypted in MPPE-Send-Key from current Radius-BS/BSIS-Access-Request/Accept message) and Terminated-BS/BSIS-Security-Block(for BSIS encrypted in MPPE-Send-Key from BSIS's previous Radius-BS/BSIS-Registration-Access-Request/Accept message). Security-Block (shown in table 1) contains Pairwise Master Key Index、 Pairwise-Master-KEY、 Key Lifetime、 ESP-Transforms-and-Authentication-Algorithms-initiator-send-Codes and ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Codes for establishing a secure connection with the BSIS .

After succeeded query process between the BS and the regional BSIS (detailed please refer to [6]). The BSIS will respond to the BS with possible neighbor BSs candidates and their BSIDs. The BS, then, tries to establish secure connections with the neighbor BSs after evaluating the coexistence relationships with these candidates. The BS sends Radius-BS/BSIS-Access-Request message to the RADIUS server to query the IP address. After getting Security-Blocks from Radius-BS/BSIS-Access-Accept messages, the BS establishes secure connections with each evaluated neighbor BS.

An access reject message may be issued due to a BS or the regional BSIS not supporting the ESP Transform or ESP Authentication algorithm selected for the following intercommunication, or for other RADIUS configuration reasons not discussed here.

Table 1 Security Block Format

Element ID	Length	Information
1	1	Pairwise Master Key Index for BS/BSIS (0-255)
2	32	Pairwise-Master-KEY
3	4*n	ESP Transforms and Authentication Algorithms initiator-send-codes which used to identify ESP algorithm codes to the regional BSIS or neighbor BS
4	4*n	ESP Transforms and Authentication Algorithms initiator-receive–codes which used to identify ESP algorithm codes from the regional BSIS or neighbor BS
5	4	Pairwise-Master-KEY Lifetime

The Security-Block would be encrypted in 32-bytes MPPE-Send-Key with the following manner ('+' indicates concatenation):

b(1) = MD5(MPPE-Send-Key+BSID)   c(1) = p(1) xor b(1) C = c(1)
b(2) = MD5(MPPE-Send-Key+BSID + c(1)) c(2) = p(2) xor b(2) C = C + c(2)
.   .
.   .
.   .
b(i) = MD5(MPPE-Send-Key+BSID + c(i-1)) c(i) = p(i) xor b(i) C = C + c(i)

Break plain text into 16 octet chunks p(1), p(2)...p(i), where i = len(P)/16. Call the ciphertext blocks c(1), c (2)...c(i) and the final ciphertext C. Intermediate values b(1), b(2)...c(i) are required. The resulting encrypted String field will contain c(1)+c(2)+...+c(i).

For Originated Security Block, the encrypted MPPE-Send-Key is from “Radius-Access-Request/Accept”.For Terminated Security Block, the encrypted MPPE-Send-Key is from “Radius-Registration-Access-Request/Accept”.

◆ RADIUS protocol messages

[replace section 6.2 with the following]

6.2 RADIUS protocol messages

The following messages are listed to support RADIUS protocol:
Note that TBD means To Be Defined.

- Radius-BS/BSIS-Registration-Request (BS/BSIS → RADIUS server): A startup BS/BSIS sends this message for authentication purpose.

Table 2 RADIUS-BS/BSIS-Registration-Access-Request

Attribute number	Attribute name	Value
1	User-Name	BSID. The BSID should be represented in ASCII format, with octet values separated by a "-". Example: "00-10-A4-23-19-C0".
4	NAS-IP-Address	BS's IP Address
6	Service-Type	Coexistence-Protocol-Register (value = TBD, ex. IAPP-Register, value = 15)
26	Vendor-Specific-Attribute (VSA)	
26-TBD	Supported-ESP-Authentication-Algorithms	The list of ESP Authentication IDs corresponding to the ESP Authentication algorithms supported by this BS (See Table 6)
26-TBD	Supported-ESP-Transforms	The list of ESP Transform IDs corresponding to the ESP transforms supported by this BS (See Table 5)
32	NAS-Identifier	BS's NAS Identifier
80	Message-Authenticator	The RADIUS message's authenticator

According to RFC 2865:2000, other RADIUS attributes may be included in the RADIUS-BS/BSIS-Registration-Access-Request packet in addition to the ones listed in Table 2.

- Radius-BS/BSIS-Registration-Accept (RADIUS server → BS/BSIS): After RADIUS server verifies the valid membership, it will respond with this accept message.

Table 3 RADIUS-BS/BSIS-Registration-Access-Accept

Attribute number	Attribute name	Value
1	User-Name	BSID.
6	Service-Type	Coexistence-Protocol -Register (value = TBD, ex. IAPP-Register, value = 15)

26	Vendor-Specific-Attribute (VSA)	
26-TBD	Supported-ESP Transforms and Authentication-Algorithms Code	The list of ESP Transforms and Authentication-Algorithms Codes approved by Radius Server
27	Session-Timeout	Number of seconds until the BS should re-issue the registration Access-Request to the RADIUS server to obtain new key information.
80	Message-Authenticator	The RADIUS message's authenticator

According to RFC 2865:2000, other RADIUS attributes may be included in the RADIUS-BS/BSIS-Registration-Access-Accept packet in addition to the ones listed in Table 3.

- Radius-BS/BSIS-Access-Request (BS/BSIS → RADIUS server): The BS sends this message to request for inter-communication with another neighbor BS or a regional BSIS.

Table 4 RADIUS-BS/BSIS- Access-Request

Attribute number	Attribute name	Value
1	User-Name	User-Name must include Country-Code、Operator ID and Regional BSIS's WM address or neighbor BS's BSID
2	User-Password	NULL.
4	NAS-IP-Address	Original BS's IP Address (the BS sending this request message)
6	Service-Type	CS/CIS-Check (value = TBD, ex. IAPP-AP-Check, value = 16)
61	NAS-Port-Type	Wireless – Other (value = 18)
80	Message-Authenticator	The RADIUS message's authenticator

According to RFC 2865:2000, other RADIUS attributes may be included in the RADIUS-BS/BSIS-Access-Request packet in addition to the ones listed in Table 4.

- Radius-BS/BSIS-Access-Accept (RADIUS server → BS/BSIS): After verifying that the neighbor BS is valid member, RADIUS server will respond with the security blocks necessary for establishing a secure connection between the neighbor BS and requesting BS or between BSIS and requesting BS.

Table 5 RADIUS-BS/BSIS- Access-Accept

Attribute number	Attribute name	Value

1	User-Name	User-Name must include Country-Code、Operator ID and Regional BSIS's WM address or neighbor BS's BSID
8	Framed-IP-Address	IP Address of Regional BSIS or neighbor BS.
26 26-TBD 26-TBD	Vendor-Specific-Attribute (VSA) Originated-BS-Security-Block Terminated-BS/BSIS-Security-Block	 Security Block encrypted using originated BS's MPPE-SEND-KEY, to be decrypted and used by the original BS Security Block encrypted using neighbor BS's MPPE-SEND-KEY (or BSIS's), to be decrypted and used by the neighbor BS (or BSIS)
80	Message-Authenticator	The RADIUS message's authenticator

According to RFC 2865:2000, other RADIUS attributes may be included in the RADIUS-BS/BSIS-Access-Accept packet in addition to the ones listed in Table 5.

Table 6 ESP Transform identifiers

Transform identifier	Value	Reference
RESERVED	0	[RFC2407]
ESP_DES_IV64	1	[RFC2407]
ESP_DES	2	[RFC2407]
ESP_3DES	3	[RFC2407]
ESP_RC5	4	[RFC2407]
ESP_IDEA	5	[RFC2407]
ESP_CAST	6	[RFC2407]
ESP_BLOWFISH	7	[RFC2407]
ESP_3IDEA	8	[RFC2407]
ESP_DES_IV32	9	[RFC2407]
ESP_RC4	10	[RFC2407]
ESP_NULL	11	[RFC2407]
ESP_AES	12	[Leech]
Reserved for privacy use	249-255	[RFC2407]

Table 7 ESP Authentication algorithm identifiers

Transform identifier	Value	Reference
RESERVED	0	[RFC2407]
HMAC-MD5	1	[RFC2407]
HMAC-SHA	2	[RFC2407]
DES-MAC	3	[RFC2407]
KPDK	4	[RFC2407]
HMAC-SHA2-256	5	[Leech]
HMAC-SHA2-384	6	[Leech]
HMAC-SHA2-512	7	[Leech]
HMAC-RIPEMD	8	[RFC2857]
RESERVED	9-61439	
Reserved for privacy use	61440-65535	

(3) Proposed enhancement of Privacy Key Management protocol usage

[insert the following section into 3.2.4.4 Privacy Key Management protocol usage]

The PKM protocol would provide a flexible and easy-to-maintain key exchange mechanism. The PKM is based on the Pairwise-Master-Key to provide a symmetric key for the PKM-Initiator and PKM-Target side.

The following figure shows the PKM Session-Key-Handshaking procedures

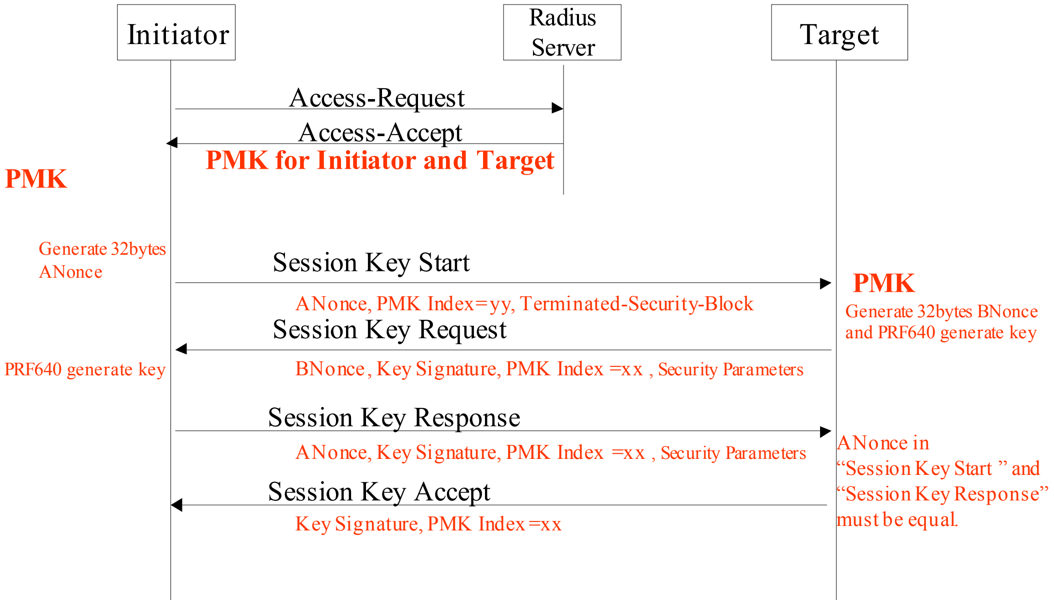

Initiator
Radius Server
Target
Access-Request
Access-Accept
PMK for Initiator and Target
PMK
Generate 32bytes ANonce
Session Key Start
ANonce, PMK Index=yy, Terminated-Security-Block
PMK
Generate 32bytes BNonce and PRF640 generate key
Session Key Request
PRF640 generate key
BNonce , Key Signature, PMK Index =xx , Security Parameters
Session Key Response
ANonce, Key Signature, PMK Index =xx , Security Parameters
ANonce in "Session Key Start " and "Session Key Response" must be equal.
Session Key Accept
Key Signature, PMK Index =xx

Figure 6 PKM Session-Key-Handshaking procedures

The PKM-Initiator will need to get the Pairwise-Master Key from Radius-Server. And then perform the following steps

(1) PKM-Initiator would get Pairwise-Master-Key-Index、Pairwise -Master-Key、ESP-Transforms-and-Authentication-Algorithms-initiator-send-Codes and ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Codes and Key-Lifetime from originated Security-Block in RADIUS-BS/BSIS- Access-Accept message and then generate a random 32-bytes ANonce.

(2) PKM-Initiator would will send Session-Key-Start message to PKM-Target with "ANonce"、"Pairwise-Master-Key-Index" and "Terminated Security-Block".

(3) After receiving Session-Key-Start message, PKM-Target would generate a random 32-bytes BNonce. And perform the PRF640 algorithm to generate the 640-bits Key. Keep the first 512-bits ESP-Transform/Authentication Keys and use the last 128-bits M-Key as the HMAC-MD5 key to generate 16-bytes Key-Signature.

(4) PKM-Target would will send Session-Key-Request message to PKM-Initiator with "BNonce"、"Pairwise-Master-Key-Index" 、"ESP-Transforms-and-Authentication-Algorithms-initiator-send-Code"(PKM-Target chosen) and "ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Code" (PKM-Target chosen)

(5) After receiving Session-Key-Request message, PKM-Initiator would perform the PRF640 algorithm to generate the 640-bits Key. Keep the first 512-bits ESP-Transform/Authentication Keys and use the last 128-bits M-Key as the HMAC-MD5 key to generate 16-bytes Key-Signature to verify the Key-Signature field on the Session-Key-Request message. If it is wrong, PKM-Initiator would perform silent-drop and doesn't response any message. If it is correct, PKM-Initiator would prepare the Session-Key-Response message and use HMAC-MD5 generate Key-Signature filed.

(6) PKM-Initiator would will send Session-Key-Response message to PKM-Target with "ANonce"、"Pairwise-Master-Key-Index" 、"ESP-Transforms-and-Authentication-Algorithms-initiator-send-Code"(PKM-Initiator chosen) and "ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Code" (PKM-Initiator chosen)

(7) After receiving Session-Key- Response message, PKM-Target would check the ANonce value if equal to the previous ANonce value in Session-Key-Start message and use HMAC-MD5 generate Key-Signature filed to verify the Key-Signature field. Compare the values of "ESP-Transforms-and-Authentication-Algorithms-initiator-send-Code" and "ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Code" to make sure the security parameters.

(8) After the above, PKM-Target will send Session-Key-Accept with Key-Signature filed to PKM-Initiator to verify.

(9) The following IP connection will use the first 512-bits ESP-Transform/Authentication Keys from PRF640 as keys and perform the ESP-Transform/Authentication algorithms from "ESP-Transforms-and-Authentication-Algorithms-initiator-send-Code" and "ESP-Transforms-and-Authentication-Algorithms-initiator-receive-Code".

The following figure shows the PKM Session-Key Re-Key procedures

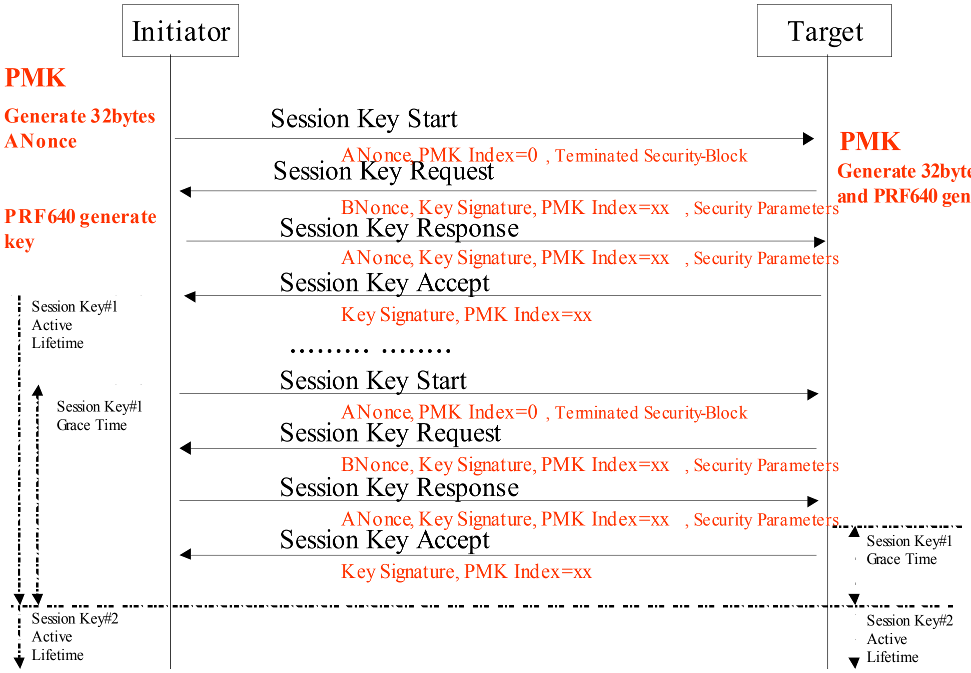

Initiator
Target
PMK
Generate 32bytes ANonce
PRF640 generate key
Session Key Start
ANonce, PMK Index=0 , Terminated Security-Block
Session Key Request
BNonce, Key Signature, PMK Index=xx , Security Parameters
Session Key Response
ANonce, Key Signature, PMK Index=xx , Security Parameters
Session Key Accept
Key Signature, PMK Index=xx
PMK
Generate 32bytes BNonce and PRF640 generate key
Session Key#1 Active Lifetime
……… ……..
Session Key Start
ANonce, PMK Index=0 , Terminated Security-Block
Session Key#1 Grace Time
Session Key Request
BNonce, Key Signature, PMK Index=xx , Security Parameters
Session Key Response
ANonce, Key Signature, PMK Index=xx , Security Parameters
Session Key#1 Grace Time
Session Key Accept
Key Signature, PMK Index=xx
Session Key#2 Active Lifetime
Session Key#2 Active Lifetime

Figure 7 PKM Session-Key Re-Key procedures

Each Session-Key would set a Key-Lifetime, and PKM-Initiator could set a Session-Key grace time to perform Session-Key-Handshaking for the next new Session-Key#2 to be generated until the end of the key lifetime. The Session-Key#1 could use up its lifetime and then activate the Session-Key#2. If each side use the Session-Key#2 first in IPsec connection, it could also activate the Session-Key#2. If the lifetime of Session-Key#1 use up, the PKM-Initiator doesn’t perform the Session-Key Re-Key procedures. PKM-Target would disconnect the IP connection until the Session-Key#2 generated.

The following figure shows the PKM Session-Key Re-Key procedures with the PMK update

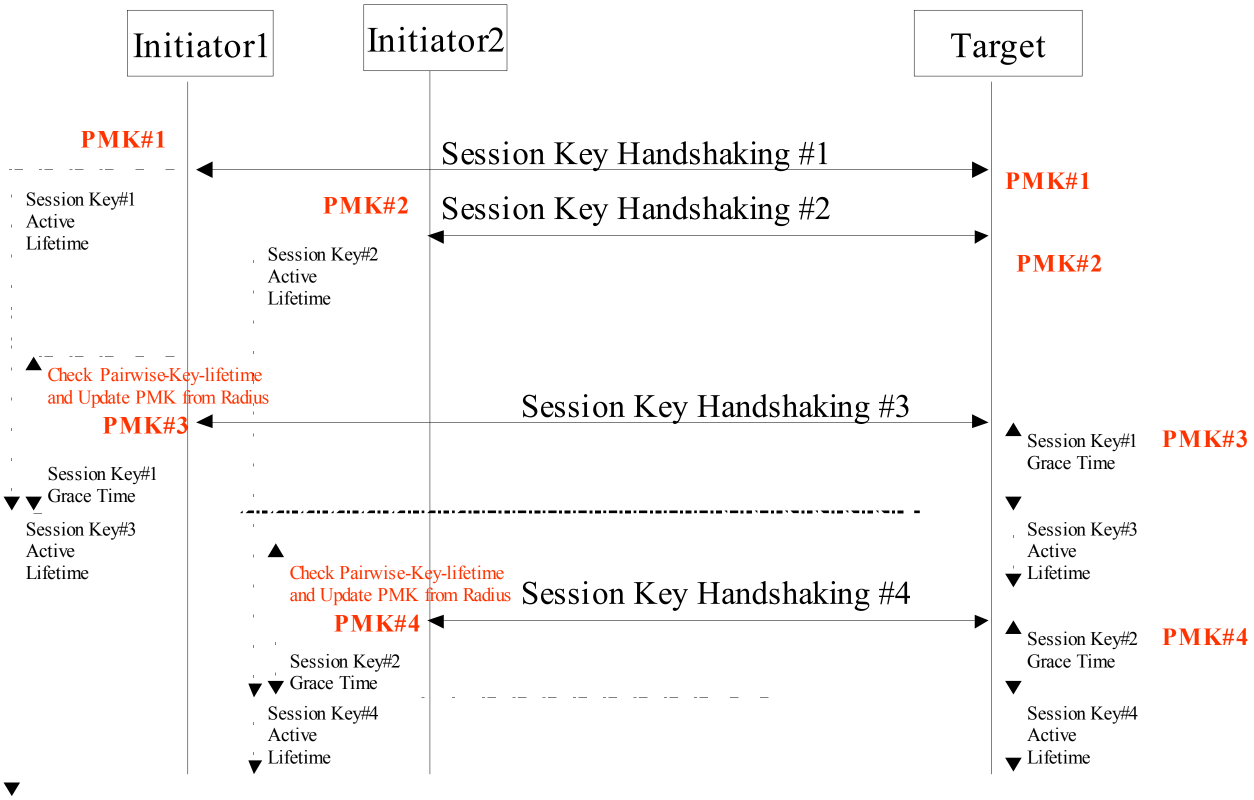


Figure 8 PKM Session-Key Re-Key procedures with the MK update of PKM-Target

The PKM-Initiator will check the current Pairwise-Key-Lifetime if still valid. If the PKM-Initiator detects the Pairwise-Key-Lifetime used up, it would perform RADIUS-BS/BSIS- Access-Request/Accept procedures to get the latest Pairwise-Master-Key in Security-Blocks from Radius-Server.

Each Pairwise-Master-Key would set a Pairwise-Master-Key-Lifetime, and BSs/BSISs could set a Pairwise-Master-Key grace time to perform Access-Request/Accept procedures for the new Pairwise-Master-Key until the end of the Pairwise-Master-Key lifetime. If the lifetime of Pairwise-Master-Key use up, the originated

BSs/BSISs don’t perform the Access-Request/Accept procedures, the terminated BSs/BSISs should discard the connections.

The following figure shows the 640-bits Key generated by PRF640

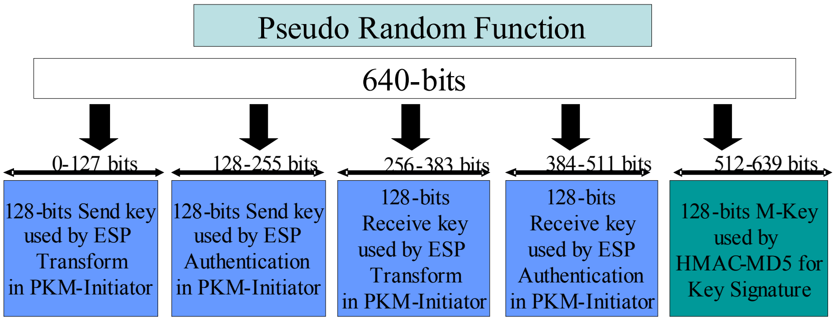

Pseudo Random Function
640-bits
0-127 bits
128-255 bits
256-383 bits
384-511 bits
512-639 bits
128-bits Send key used by ESP Transform in PKM-Initiator
128-bits Send key used by ESP Authentication in PKM-Initiator
128-bits Receive key used by ESP Transform in PKM-Initiator
128-bits Receive key used by ESP Authentication in PKM-Initiator
128-bits M-Key used by HMAC-MD5 for Key Signature

Figure 9 the 640-bits Key generated by PRF640

The BSs/BSISs get Pairwise-Master-Key from Radius-Servers and generate 32-bytes Nonce value to derive 640-bits key as follows

PRF-640(MK, "BS-BSIS key expansion", Min(BS1ID,BS2ID) || Max (BS1ID,BS2ID)|| Min (ANonce,BNonce) || Max(ANonce,BNonce))

Where

```
PRF-640 (K,A,B) =
    for i=0 to 4 do
        R=R|HMAC-SHA-1(K, A|0|B|I)
    return LeastSignificant-640-bits( R )
```

and “|” denotes bitstring concatenation

◆ Privacy Key Management protocol messages

[insert the following section into 6.3 Privacy Key Management protocol messages]

In order to easily recognize and maintain ESP Transform identifiers and ESP Authentication algorithm identifiers, a 32-bits ESP-Transforms-and-Authentication-Algorithms-Code could be used in PKM protocol. Each Transform and Authentication algorithm identifiers need a 8-bits identifier (See table 5 and 6) to record which algorithm used to Transform/Authentication. For the PKM-Initiator/Target to negotiate the ESP-Transform/Authentication algorithm in the following IP-connection, the ESP-Transforms-and-Authentication-Algorithms-Codes could be placed in the PKM message for the each-side to decide acceptable algorithms.

The following figure shows the 32-bits ESP-Transforms-and-Authentication-Algorithms-Code format

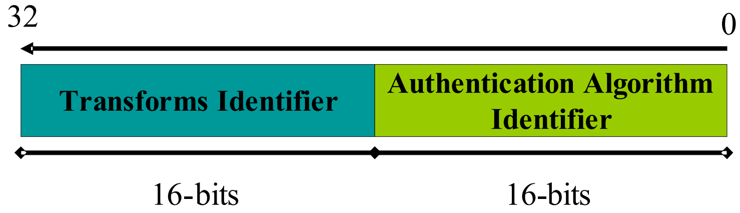


Figure 10 32-bits ESP-Transforms-and-Authentication-Algorithms-Code format

The PKM protocol procedures contain 4 message actions, and each-side could check the code value of the begin of PKM message to recognize which action need to perform this moment. The meaning of codes for

PKM message as follows

- 0 = Session Key Start
- 1 = Session Key Request
- 2 = Session Key Response
- 3 = Session Key Accept

The PKM message uses TLV format to add the following attributes

Table 8 Session Key frame TLV

Type	Length	Value Information
1	32	Nonce
2	8	Replay Counter
3	8	Key lifetime in seconds
4	16	Key Signature
5	1	Security Parameter Index
6	4*n	ESP Transforms and Authentication-Algorithms initiator-send-Codes (Codes Number *4)
7	4*n	ESP Transforms and Authentication-Algorithms initiator-receive-Codes (Codes Number *4)
8	33 + 4*n	Security Block

The Length field contains a 16-bits value to record the whole frames size starting from Code field, with the ESP-Transforms-and-Authentication-Algorithms-Codes field filled in if present.

The PMK-Index field contains a 8-bits value to record the current Pairwise-Master-Key-Index each PKM-side used. If the PKM-Target detects the PMK-Index different of PKM-Initiator, it must update the latest Pairwise-Master-Key.

The Replay-Counter field contains a 64-bits random number (such as 64-bit NTP timestamp) and does not repeat within the life of the Master-Key material.

The Key-Lifetime field contains a 64-bits value to record the Session-Key lifetime in seconds.

The Key-Signature field contains an HMAC-MD5 message integrity check computed over the Session-Key-Frame starting from Code field, with the ESP-Transforms-and-Authentication-Algorithms-Codes field filled in if present, but with the Key Signature field set to zero. The M-Key is used as the HMAC-MD5 key.

The Security-Parameters-Index field contains a 32-bits value to assign to the IPsec Security Association (including the encryption and authentication keys, the authentication algorithm for AH and ESP, the encryption algorithm for ESP, the lifetime of encryption keys…etc in this session). PKM-Initiator/Target could check the

SPI value in ESP-Header or AH-Header to detect to use which SA for this IPsec connection.

The ESP-Transforms-and-Authentication-Algorithms-Codes field contains 8-bits Codes-Number value to record the number of ESP-Transforms-and-Authentication-Algorithms-initiator-send/receive-Codes, each length of ESP-Transforms-and-Authentication-Algorithms-Codes is 4-bytes. The BSs/BSISs would compare each ESP-Transforms-and-Authentication-Algorithms-initiator-send/receive-Code to find out which code is supported.

The following figure shows the Session-Key-Start message format

Code(1) =0	**Length(2)**	**PMK** **Index**(1)	Source_BSSID(6)	Destination_BSSID(6)
TLV Attributes…… NONCE (**32**) Security Parameters Index **(4)** Terminated Security Block (**33 + 4*n**)				

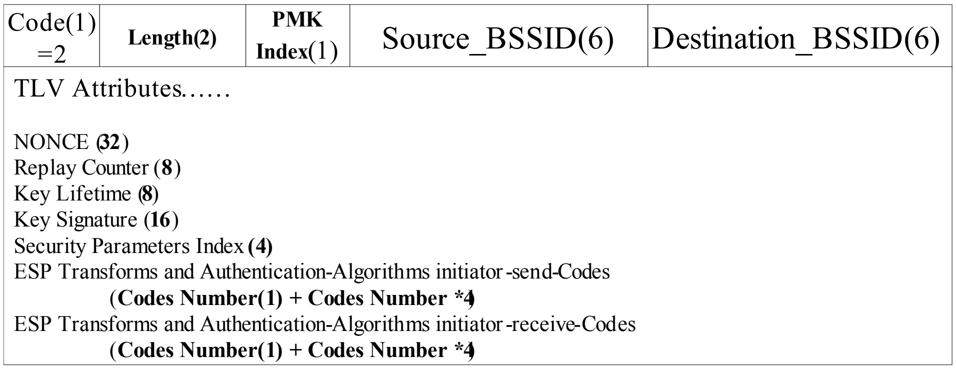
Figure 11 Session-Key-Start message format

The following figure shows the Session-Key-Request message format

Code(1) =1	**Length(2)**	**PMK** **Index**(1)	Source_BSSID(6)	Destination_BSSID(6)
TLV Attributes….. NONCE (**32**) Replay Counter (**8**) Key Lifetime (**8**) Key Signature (**16**) Security Parameters Index **(4)** ESP Transforms and Authentication-Algorithms initiator-send-Codes **(Codes Number(1) + Codes Number *4)** ESP Transforms and Authentication-Algorithms initiator-receive-Codes **(Codes Number(1) + Codes Number *4)**				

Figure 12 Session-Key-Request message format

The following figure shows the Session-Key-Response message format



Code(1) =2	**Length(2)**	**PMK** **Index**(1)	Source_BSSID(6)	Destination_BSSID(6)
TLV Attributes…… NONCE (**32**) Replay Counter (**8**) Key Lifetime (**8**) Key Signature (**16**) Security Parameters Index **(4)** ESP Transforms and Authentication-Algorithms initiator-send-Codes (**Codes Number(1) + Codes Number *4**) ESP Transforms and Authentication-Algorithms initiator-receive-Codes (**Codes Number(1) + Codes Number *4**)				

Figure 13 Session-Key-Response message format

The following figure shows the Session-Key-Accept message format

Code(1) =3	**Length(2)**	**PMK** **Index**(1)	Source_BSSID(6)	Destination_BSSID(6)
TLV Attributes…… Replay Counter (**8**) Key Signature (**16**)				

Figure 14 Session-Key-Accept message format

References

[1] IEEE C802.16h – 05/012r1 –General Architecture for Inter-network Communication Across 802.16 LE Systems, 2005-04-29

[2] IEEE Std 802.11F-2003, IEEE Trial-Use Recommended Practice for Multi-Vendor Access Point Interoperability via an Inter-Access Point Protocol Across Distribution Systems Supporting IEEE 802.11™ Operation.