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Secure Authentication & Key Establishment protocol with perfect Forward Secrecy for Multi and Broad cast service in IEEE 802.16e

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I. Introduction

The Multicast and Broadcast service offers the possibility to distribute data to multiple M.S. with one single message. This saves cost and bandwidth. Broadcasted messages in IEEE 802.16e are encrypted symmetrically with a shared key [1]. Every member in the group knows the key & can decrypt the traffic. Message authentication is also based on the same shared key. This algorithm contains the vulnerability that every group member, besides decrypting and verifying broadcast messages, can also encrypt and authenticate messages as if they originate from the legitimate B.S [1, 3, 4, 5]. Another aspect which is much more problematic is the distribution of the traffic encryption keys (GTEKs), when the optional Multicast and Broadcast Rekeying Algorithm (MBRA) is used [6]. To transfer a GTEK to all group members it is broadcasted but encrypted with the key encryption key (GKEK). Due to broadcasting, the GKEK must also be a shared key and every group member knows it [1]. Thus are adversary group member can use it to generate valid encrypted and authenticated GTEK key update command messages & distribute an own GTEK [1]. Every group member would establish the adversary's key as a valid next GTEK. [1] Subsequently all traffic sent by the legitimate B.S can no longer be decrypted by the M.S. From M.Ss point of view only traffic from the adversary is valid. To force M.Ss to establish the adversary's key, there are several possibilities; If the implementation does not work properly, the key from the latter of two subsequently sent GTEK update command messages may overwrite the former one. Hence, the adversary just has to send its GTEK update command message after the B.S broadcasted a key update message. If the implementation follows the standard, the keys of both messages are accepted [1]. To be sure the M.S will not establish the legitimate B.Ss key; an intruder could forge some part of the B.Ss GTEK update command message [1]; Such a changed message would not be verified as correct and discarded by the M.Ss. After this, the adversary can send its own GTEK update command message which will be accepted [1, 7]. In a unicast connection, this different keying material at the mobile station would be detected as the B.S cannot decrypt data sent by the M.S. This result in a TEK invalid message destined to the M.S which subsequently refreshes its keying material [1]. Since the M.Bs is only unidirectional so; the B.S unable to detect that M.S has different GTEKs.

II. Shared Key in Multicast and Broadcast Service

A shared key cannot be used as every group member can forge messages when having the current symmetric keys [1]. Instead the GTEK update command message could be sent to each M.S in a unicast way like the GKEK update command message [1]. The key should then be encrypted with the M.S related KEK which is only known by this individual M.S. The BS sends the GTEK update command message by itself

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when the current key's lifetime is going to expire [1]. The Fig.1 shows this. Another solution is the use of public key cryptography. Here, the GTEK update command message remains broadcasted and encrypted with the shared key GKEK but is additionally signed by an asymmetric signature [1]. M.Ss receiving a GTEK update command message can verify the signature of the B.S and subsequently decrypt the GTEK with the shared GKEK [1]. The Fig.2 shows this method together with the unicasted GKEK update command message.

A third possibility is to generate GTEKs as part of a one way hash chaining function (Fig. 3). Here the B.S has to generate a random number which represents the initial key GTEK0 [1]. Then the other GTEKs are generated by applying a one way hash function to previous GTEKs respectively. This is iterated n times.

GTEK0 = random ()
GTEK1 = f (GTEK0)
GTEK2 = f (GTEK1)
GTEKn = f (GTEKn-1)

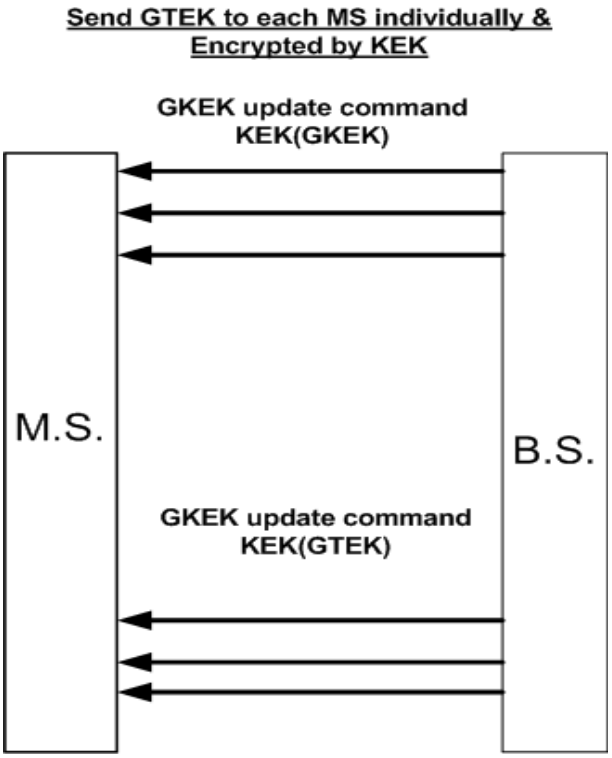

Fig.1 : Possible solution to transmit GTEK in a secure Way

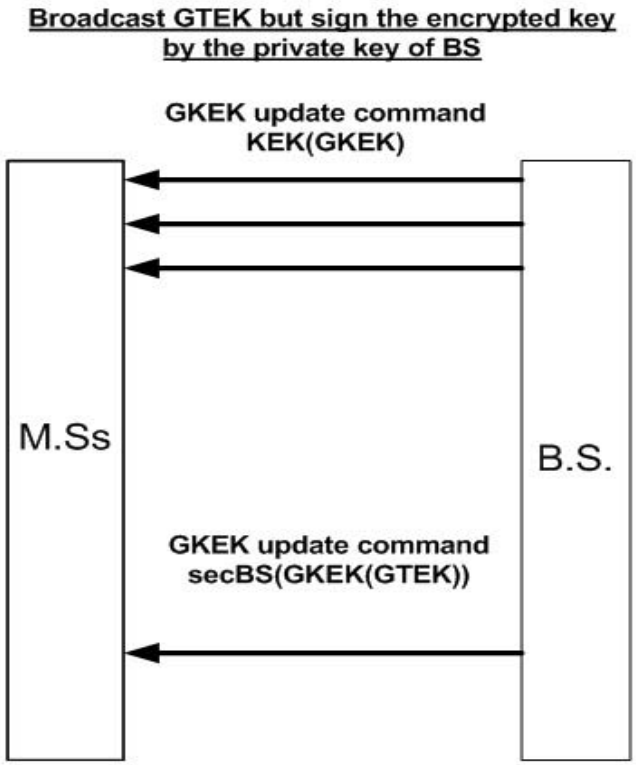

Fig.2 : Possible solution to transmit GTEK in a secure Way

To apply this algorithm, the key GKEK update command message has to be capable of transporting GKEK and GTEK keys together [1]. The design of the key update command message already includes both keys so only a little modification is needed here. Additionally the GTEK state machine at B.S must generate the GTEK hash chain & store all the keys. The GTEK state machine at M.S must add the functionality to authenticate GTEK keys by calculating the hash function and comparing it to the previous key [1]. A drawback of this algorithm is that it has a reduced forward secrecy [1]. This means a M.S joining the group can decrypt all broadcasted data since the last hash chain generation. If forward secrecy is crucial, the hash chain has to be regenerated each time a M.S enters the group [1]. When using an asymmetric signature or a hash chain to authenticate the GTEK transfer, only one message is needed to update the keys of all M.S due to broadcasting [1]. Thus the introduced traffic in these solutions is constant and does not depend on the number of members in the group [1]. Another important fact is that, for unicasting the computing power requirement is very low. Because here the M.S just have to verify the HMAC & save the keys [1]. Also the use of a hash chain does not require much computation. Here the M.S has to calculate the hash function of the received key and compare it with the saved key [1].

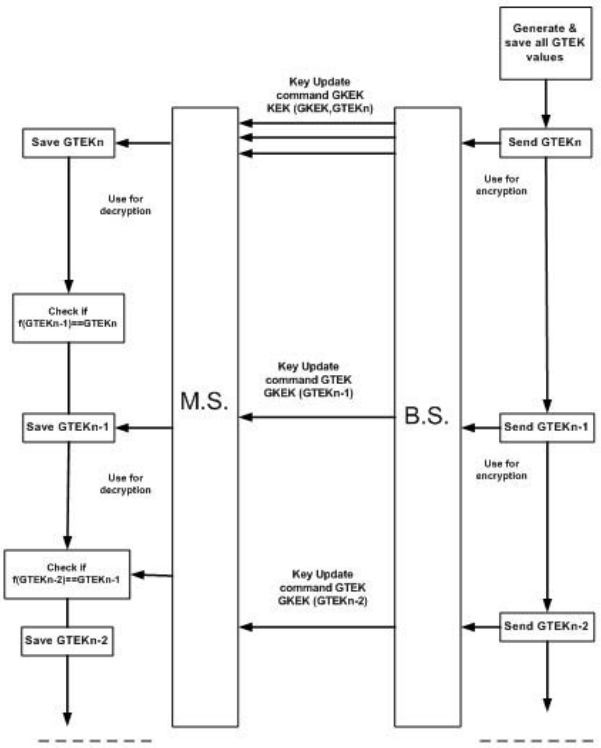

Fig.3 : Avoid key forgery by a GTEK hash chain

III. The Proposed Protocols

In this section, we propose three user authentication with key establishment protocols (UAKE) satisfying: Class-1, Class-3, and Class-7 PFS. The proposed protocols only use one-way hash functions & exclusive-or (XOR) operations. Each proposed protocol involves two phases: 1) the initialization phase 2) the user authentication with key establishment phase. Table I shows the notations used throughout our protocols.

Table 1 : The notations used in our Protocols

Notations	Description
MD	the mobile device
S	the authentication server
AS	the application server
ID_{MD}	the identity of MD
ID_S	the identity of S
ID_{AS}	the identity of AS
x	a secret key held by the
PW_{MD}	the password of MD
S_{AS}	the shared key between S and AS
$h(\cdot)$	a secure one-way hash function
$\|\|$	string concatenation operation
$\oplus$	exclusive-or operation

a) The Proposed UAKE Protocol with Class-1 PFS

In this protocol, an attacker cannot obtain the previous session keys even if PW_{MD} and S_{AS} are both disclosed. Details are given with the following steps.

i. *The initialization phase:*

In this protocol, S computes $A_{MD} = h(ID_{MD} || x)$ and stores it in MD. Moreover, S computes $A_{AS} = h(ID_{AS} || x)$ and sends it to AS via a secure channel.

ii. *User authentication with key establishment phase:*

Step 1. MD generates a random number R_{MD} to compute $M_1 = A_{MD} \oplus R_{MD}$ and $M_{1\_MAC} = h(ID_{MD} || R_{MD}) \oplus PW_{MD}$. Then MD sends (ID_{MD}, ID_{AS}, M_1, M_{1_MAC}) to AS.

Step 2. After receiving (ID_{MD}, ID_{AS}, M_1, M_{1_MAC}), AS generates a random number R_{AS} to compute $M_2 = A_{AS} \oplus R_{AS}$ and $M_{2\_MAC} = h(ID_{AS} || R_{AS}) \oplus S_{AS}$. Then AS sends (ID_{MD}, M_1, M_{1_MAC}, M_2, M_{2_MAC}) to S.

Step 3. S computes $R_{MD} = M_1 \oplus h(ID_{MS} || x)$ and $R_{AS} = M_2 \oplus h(ID_{AS} || x)$ using its secret key x. Then S checks whether M_{1_MAC} and M_{2_MAC} are the same with $h(ID_{MD} || R_{MD}) \oplus PW_{MD}$ and $h(ID_{AS} || R_{AS}) \oplus S_{AS}$, respectively. If both verifies pass, step 4 is then performed. Otherwise, S denies this request.

Step 4. Next, S generates a session key K to compute $M_{MD} = h(R_{MD}) \oplus K$, $M_{MD\_MAC} = h(R_{MD} || K)$, $M_{AS} = h(R_{AS}) \oplus K$ and $M_{AS\_MAC} = h(R_{AS} || K)$. Then, S sends ($ID_{MD}$, M_{MD}, M_{MD_MAC}, ID_{AS}, M_{AS}, M_{AS_MAC}) to AS.

Step 5. As computes $K = MD_{AS} \oplus h(R_{AS})$ and checks whether M_{AS_MAC} is the same with $h(R_{AS} || K)$. If they are the same, AS can obtain the session key K and then sends (ID_{MD}, M_{MD}, M_{MD_MAC}) to MD.

Step 6. After receiving (ID_{MD}, M_{MD}, M_{MD_MAC}), MD computes $K = M_{MD} \oplus h(R_{MD})$ and checks whether M_{MD_MAC} is the same with $h(R_{MD} || K)$. If they are the same, MD also can obtain K.

b) The Proposed UAKE Protocol with Class-7 PFS

In this protocol, an attacker cannot get the previous session keys even if PW_{MD}, S_{AS}, and x are all disclosed. The process is explained below.

i. *The initialization phase:*

Before the protocol begins, S computes $A_{MD} = h(ID_{MD} // x)$ and stores it in MD. Also, S computes $A_{AS} = h(ID_{AS} // x)$ and sends it to AS via a secure channel.

ii. *User authentication with key agreement phase:*

Step 1. MD chooses a large prime p, a primitive

element g in Galois filed GF (p) and a random number d ∈ [1, p-1]. Then, MD computes M1 = AMD⊕ g^d and M_{1_MAC} = h(ID_{MD} || g^d) ⊕ PW_{MD}, and sends

Step 2. After receiving *(ID_{MD}, ID_{AS}, p, g, M_1, M_{1_MAC})*, *AS* chooses a random number a ∈ [1, p-1] to compute M_2 = A_{AS} ⊕ g^a and M_{2_MAC} = h(ID_{AS} || g^d) ⊕ S_{AS}. Then AS sends *(ID_{MD}, p, g ,M_1, M_{1_MAC}, ID_{AS}, M_2, M_{2_MAC})* to *S*.

Step 3. S computes g^d = M_1 ⊕ h(IDMD || x) and g^a = M_2 ⊕ h(IDAS || x) using its secret key x. Then S verifies whether M1_MAC and M2_MAC are equal to h(IDMS || g^d) ⊕ PWMD and h(IDAS || g^a) ⊕ SAS respectively. If they are both equal, step 4 is subsequently carried out. Otherwise, S denies this request.

Step 4. S chooses a random number s∈[1, p-1] to compute k_{CS} = $(g^a)^s$ = g^{as} and k_{AS} = $(g^d)^s$ = g^{ds}. Then S computes M_{MD} = k_{CS} ⊕ g^d, M_{MD_MAC} = h(k_{CS} || g^d), MAS = kAS ⊕ g^a and MAS_MAC = h(kAS || g^a) sends them to AS.

Step 5. After receiving *(ID_{MD}, M_{MD}, M_{MD_MAC}, ID_{AS}, M_{AS}, M_{AS_MAC})*, *AS* computes k_{AS} = M_{AS} ⊕ g^a and verifies whether MAS_MAC equals to *h(k_{AS} || g^a)*. If it holds, AS can compute the session key K from *K* = *(K_{AS})^a* = *(g^{ds})^a* = *g^{ads}*. Then *AS* sends *(ID_{MD}, M_{MD}, M_{MD_MAC})* to *MD*.

Step 6. *MD* computes k_{CS} = M_{MD} ⊕ g^d and verifies whether M_{MD_MAC} equals to *h(k_{CS} || g^d)*. If they are equal, *MD* can compute the session key *K* from *K* = *(k_{CS})^d* = *(g^{as})^d* = *g^{ads}*.

The proposed protocols only use one-way hash functions and XOR operations. Moreover, the proposed protocols also provide three kinds of PFS to meet different requirements. Therefore, compared with Sun and Yeh's protocols, our protocols are more efficient and practical for mobile devices. Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit- mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

IV. Security Analysis and Discussions

In this section, we discuss some potential attacks which might occur on the proposed protocols.

a) Replay attack

The replay attack is an attack in which an attacker can use the previous eavesdropped messages to login the server without being detected [8]. Now, we are going to demonstrate in this subsection that, the proposed protocols can successfully withstand the replay attack.

i. *The proposed UAKE protocol with Class-1 PFS:*

After sending *(ID_{MD}, ID_{AS}, M_1, M_{1_MAC})* to S, an attacker can get M_{MD} in Step 4. However, the attacker can't have A_{MD} = *h(ID_{MD} || x)* that contains a secret key x protected by one-way hashing function. This also means that he cannot extract R_{MD} to obtain *K* or PW_{MD} by computing *K* = M_{MD} ⊕R_{MD} or PW_{MD} = *h(ID_{MD} || R_{MD})* ⊕M_{1_MAC}. Thus, this protocol can prevent the replay attack.

ii. *The proposed UAKE protocol with Class-3 PFS:*

An attacker replays *(ID_{MD}, ID_{AS}, M_1, M_{1_MAC})* to *AS* in Step 1 and receives *(ID_{MD}, M_{MD}, M_{MD_MAC})* in Step 5. Because both A_{MD} and R_{MD} are unknown, the attacker cannot extract *K* or PW_{MD}. As a result, the replay attack cannot *be* mounted in this protocol.

iii. *The proposed UAKE protocol with Class-7 PFS:*

Even if an attacker sends *(ID_{MD}, ID_{AS}, M_1, M_{1_MAC})* to *AS* in Step 1, he cannot obtain *K* or PW_{MD} from *AS*'s reply. Without A_{MD}, the attacker cannot obtain g^d by computing g^d = M_1 ⊕A_{MD}. Also, the attacker faces the discrete logarithm problem in computing d. Thus, it is quite impossible for the replay attack to occur in this protocol.

b) Password guessing attack

This attack refers to an intruder attempts to pass the authentication with certain guessed password [9, 10, 11]. The following discussions show, how the proposed protocols can prevent the password guessing attack.

i. *The proposed UAKE protocol with Class-1 PFS:*

An intruder tries to send the eavesdropped message M_1 and $M^*_{1\_MAC}$ = *h(ID_{MD} || R^*_{MD})* ⊕PW^*_{MD} to *S* in Step 1, where R^*_{MD} and PW^*_{MD} are generated by the intruder. In Step 2, *S* extracts R_{MD} = M_1 ⊕*h(ID_{MD} || R_{MD})* to check whether $M^*_{1\_MAC}$ is the same with *h(ID_{MD} || R_{MD})* ⊕PW_{MD} [9]. The result is S will find the equation is not correct and then refuse the request. Moreover, the intruder has no extra information to verify the guessed password PW^*_{MD}. Therefore, the password guessing attack does not work in this protocol.

ii. *The proposed UAKE protocol with Class-3 PFS:*

Assume that an intruder replays the eavesdropped message M_1 and $M^*_{1\_MAC}$ = *h(ID_{MD} || R^*_{MD})* ⊕PW^*_{MD} to *AS* in Step 1, where R^*_{MD} and PW^*_{MD} are generated by the intruder. If PW^*_{MD} and R^*_{MD} are not correct, *S* will detect this failure and stop the request in Step 3. Thus, the password guessing attack is prevented.

iii. *The proposed UAKE protocol with Class-7 PFS:*

An intruder attempts to send the eavesdropped message M_1, $M^*_{1\_MAC}$ = *h(ID_{MD} || g^*)* ⊕PW^*_{MD} to *AS* in

Step 1, where g^* and PW^*_{MD} are generated by the intruder. However, in Step 3, S will detect the failed login by verifying M_{1_MAC} because g^* and PW^*_{MD} are not correct. Therefore, the intruder has no chance to perform the password guessing attack .

c) Perfect forward secrecy

We show, as follows that the proposed protocols can satisfy Class-1, Class-3 and Class-7 PFS [12].

i. *The proposed UAKE protocol with Class-1 PFS:*

When MD's password PW_{MD} is disclosed, an attacker only can derive $h(ID_{MD} \,||\, R_{MD}) = M_{1\_MAC} \oplus PW_{MD}$. However, the attacker cannot further get the session key K by computing $K = h(R_{MD}) \oplus M_{MD}$ without A_{MD} [12]. Thus, this protocol can provide Class-1 PFS.

ii. *The proposed UAKE protocol with Class-3 PFS:*

When PW_{MD} and S_{AS} are disclosed, an attacker can obtain $h(ID_{MD} \,||\, R_{MD}) = M_{1\_MAC} \oplus PW_{MD}$ and $h(ID_{AS} \,||\, R_{AS}) = M_{2\_MAC} \oplus S_{AS}$. However, the attacker still cannot know A_{MD} and A_{AS}, which are stored in MD and AS respectively [16]. Consequently, the attacker cannot extract R_{MD} and R_{AS} from $M_1 = A_{MD} \oplus R_{MD}$ and $M_2 = A_{AS} \oplus R_{AS}$. That is, the attacker cannot get the session key K by computing $K = M_{MD} \oplus h(R_{MD})$ or $K = M_{AS} \oplus h(R_{AS})$. This protocol can provide Class-3 PFS [16].

iii. *The proposed UAKE protocol with Class-7 PFS:*

When PW_{MD}, S_{AS} and x are all disclosed, an attacker can obtain g^d and g^a by $g^d = M_1 \oplus h(ID_{MD} \,||\, x)$ and $g^a = M_2 \oplus h(ID_{AS} \,||\, x)$. Moreover, the attacker can derive $k_{CS} = M_{MD} \oplus g^d$ and $k_{AS} = M_{AS} \oplus g^a$. To get the session key $K = g^{ads}$, the attacker has to solve Diffie-Hellman problem [16]. Nevertheless, this is hard to be accomplished. Therefore, this protocol can provide Class-7 PFS.

V. Conclusion

Secured data transmission is one of the prime aspects of wireless networks as they are much more vulnerable to security attacks. In this paper, we explore the possibility of key forgery in Multi- and Broadcast service. We proposed three UAKE protocols with PFS based upon one-way hash functions and XOR operations. The computation loads and power supply requirements are less, which make this protocol more efficient and suitable than other.

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