**3GPP TSG SA WG3 Security** **S3-020341**

**July 9 – July 12, 2002**

**Helsinki, Finland**

**Agenda Item:** 7.9

**Source:** Ericsson

**Title:** Introduction of IEEE 802.11 Security

**Document for:** Discussion

# 1. Scope and objectives

This document attempts to give a brief overview of the current status in IEEE 802 and in particular in the Enhanced Security Task Group IEEE 802.11i. Note that IEEE 802.11i is still a draft and that the content therefore may change before it reaches approval as a standard.

# 2 Introduction

## IEEE 802

IEEE Project 802 develops LAN and MAN standards, mainly for the lowest 2 layers of the OSI Reference Model. IEEE 802.11 is the Wireless LAN Working Group (WG) within Project 802. The existing 802.11 standard with amendments are:

- 802.11 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications
- 802.11a High-speed Physical Layer in the 5 GHz Band.
- 802.11b Higher-Speed Physical Layer Extension in the 2.4 GHz Band.
- 802.11d Specification for operation in additional regulatory domains.

Currently there are a number of Task Groups (TG) in the 802.11 WG that each work on new amendments to the standard:

- 802.11e Medium Access Control (MAC) Enhancements for Quality of Service (QoS).
- 802.11f Inter Access Point Protocol (IAPP). (A recommended practice, not a standard).
- 802.11g Higher-Speed Physical Layer Extension in the 2.4 GHz Band
- 802.11h Spectrum and Power Management extensions in the 5 GHz band in Europe.
- 802.11i Specification for Enhanced Security.

Membership in IEEE 802.11 is individual (i.e. not based on company) and anyone that has been present at a certain number of meetings becomes member in the WG. Membership is required in order to get voting rights and all members have one vote (again, votes are not company based).

# 3 Authentication

## Legacy 802.11 authentication

The 802.11-1999 authentication mechanism works at the data link layer (MAC layer). Two authentication methods exist, open system authentication and shared key authentication. Open system authentication is in principle a null authentication scheme and accepts anyone that requests authentication.

Shared key authentication is a challenge-response authentication based on a shared secret. The mobile station sends an Authentication request to the Access Point (AP). The Access Point sends a chosen plaintext string to the station and the station responds with the WEP-encrypted string. (See below for more details on WEP). If the string is correctly encrypted the AP sends an Authentication message to the station to indicate that the authentication was successful. The standard allows for up to four keys in a cell but in practice all communication parties in the cell share the same secret. Note that the authentication is not mutual, only the mobile terminals are authenticated. Shared key authentication is very weak. An attacker that listens to a successful authentication exchange will have all elements that are needed to successfully perform an authentication of his/her own, even if the shared key is unknown. Today shared key authentication is not considered useful.

## IEEE 802.1X and EAP

The 802.11i Task Group (TGi) within IEEE is working on enhancements to the 802.11 security [802.11i]. It has been decided to use IEEE 802.1X as the authentication framework [802.1X]. IEEE 802.1X in turn uses the Extensible Authentication Protocol (EAP) that allows for end-to-end mutual authentication between a Mobile Station and an Authentication Server [EAP]. Thus, even though 802.11i still performs access control on layer 2, the authentication message exchange is not restricted to the MAC layer but uses other IEEE standard as well as IETF standards.

IEEE 802.1X is a standard for port-based access control. IEEE 802.1X can be described to lie between the MAC layer and higher layers and takes care of filtering of frames to/from non-authenticated stations. Before authentication is completed only EAP-traffic is allowed to pass. This allows an authentication exchange to cross the Access Point before general data is allowed to pass. When the 802.1X entity in the Access Point (AP) is informed that a mobile station has successfully authenticated, the AP starts to forward data packets to/from that station.

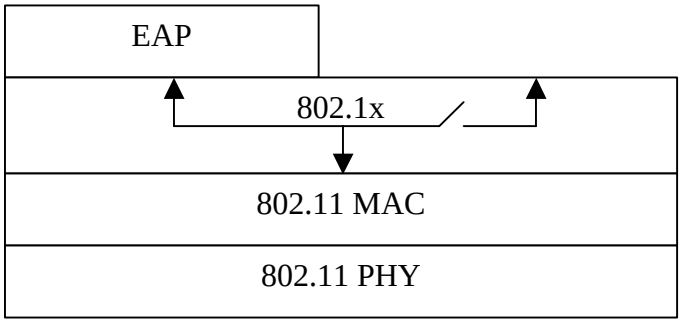


**Figure 1 IEEE 802.1X in part of protocol stack in Access Point or mobile station. EAP messages are always accepted while other packets are filtered based on authentication status.**

EAP allows for end-to-end authentication between a Mobile Station and an Authentication Server (AS). EAP is a generic protocol that allows different authentication mechanisms (called EAP methods) to be transported. EAP has a general part [EAP] that describes the general packet format and header content. Each EAP method then has a more specific description for how the actual authentication mechanism is carried by the EAP packets. The EAP packets can then be transported over different protocols. In 802.1X a special frame format called EAP over LAN (EAPOL) is defined for sending EAP messages over 802 links. This allows EAP messages to be sent over the LAN before higher layer protocols, e.g. IP, have been initiated. Between the Access Point (AP) and the AS, EAP messages are typically encapsulated in an AAA protocol, e.g. in RADIUS or DIAMETER (see Figure 2). It is out of the scope of 802.11i to specify a certain AAA protocol. IEEE 802.11i can in principle also be used without AAA protocol if the EAP method is implemented in the AP.

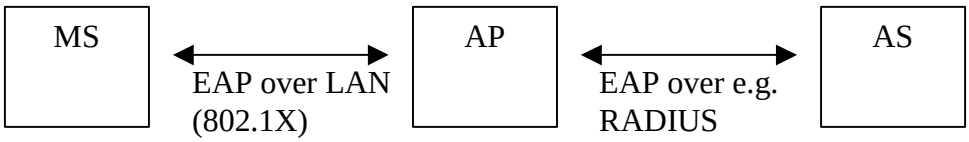


**Figure 2 Example of end-to-end authentication using EAP.**

Examples of EAP methods (RFCs or Internet Drafts) are:

- EAP-SIM for SIM-based authentication. (Internet Draft) [EAP-SIM].
- EAP-AKA for SIM and USIM-based authentication (Internet Draft) [EAP-AKA].
- EAP-TLS for certificate-based authentication (RFC) [EAP-TLS].

The actual EAP authentication takes place between the MS and the AS and is in principle transparent to the AP. The AP only has to forward EAP messages: EAPOL-encapsulated on the wireless side and e.g. RADIUS-encapsulated on the wired side. If authentication is successful, the AS sends a RADIUS-Access Accept message to the AP (in the case RADIUS is used as AAA protocol). The AP then knows that the MS has been authenticated and can start forwarding traffic to/from the MS. After reception of the Access-Accept message from the AS, the AP sends an EAP-Success message to the MS (see Figure 3).

## Key management

To use an EAP method with 802.11i it is required that a 256-bit master key is established as part of the authentication process. Many EAP methods generate key material as part of the authentication (e.g. EAP-SIM, EAP-AKA, EAP-TLS) but the exact way in which the master key is generated depends on the EAP method and is outside the scope of 802.11i. After the EAP authentication is finished, both the MS and the AS will know the master key. If RADIUS is used, the AS then sends the master key to the AP as an attribute in the RADIUS-Access Accept message. The MS and AP use the master key to derive session keys for encryption and integrity protection, as specified in 802.11i. This provides unique unicast keys for each MS-AP association.

The broadcast/multicast key in a cell is generated by the AP and sent in an EAPOL-Key message (defined in 802.1X) to each station. To protect the broadcast/multicast key the EAPOL packet is encrypted with TKIP or AES (see below) using the unicast key. The AP can in principle update the broadcast/multicast key any time, e.g. when a MS leaves the cell.

It shall also be possible to use a pre-shared key instead of the EAP master key material.

## Message exchange (example with RADIUS)

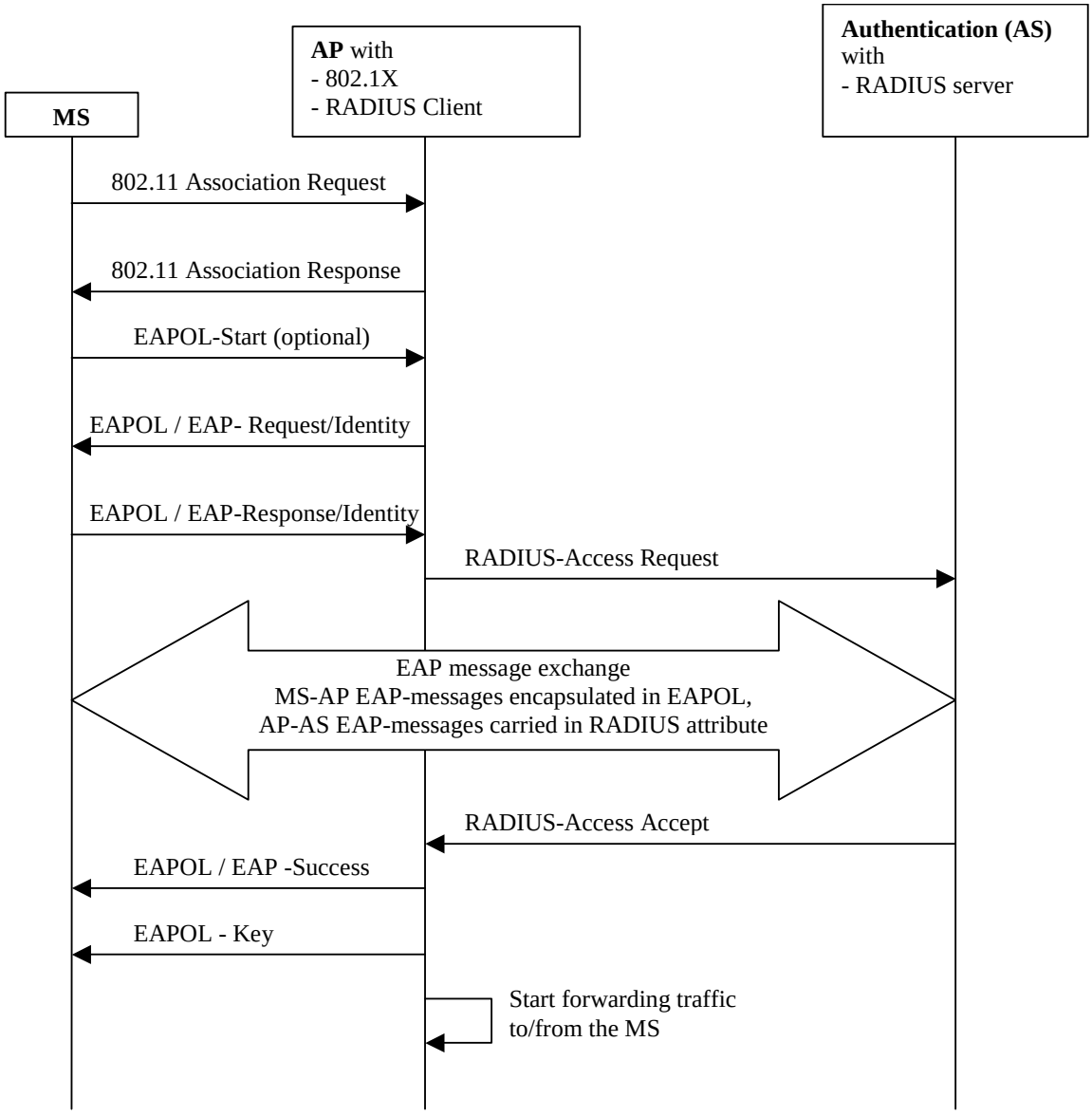


**Figure 3 General EAP authentication with 802.11i and RADIUS as AAA protocol.**

# 4 Encryption and integrity protection

The air-link protection in IEEE 802.11 occurs in the MAC layer. This means that all layer-2 data frames, including LAN broadcasts, are protected. The 802.11-1999 standard specifies the Wired Equivalent Privacy (WEP) for encryption and integrity protection. The 802.11i task group is specifying two new encryption/integrity-protection protocols, the Temporal Key Integrity Protocol (TKIP) and the Wireless Robust Authenticated Protocol (WRAP). The 802.1X/EAP authentication

mechanism can in principle be used with any of the three encryption protocols but configuration can restrict the number of allowed encryption protocols in a cell.

In order to be backwards compatible, an 802.11i-capable cell could support several encryption protocols simultaneously. For example, to support legacy stations a manually configured shared WEP key may need to be used for those stations. This key will then also be used as broadcast/multicast key for 802.11i-capable stations that instead use unique pair-wise keys for unicast traffic.

## WEP

The IEEE 802.11-1999 Standard specified the Wireless Equivalent Privacy (WEP). WEP uses RC4 with a 40-bit key and 24-bit initialisation vector (IV) for encryption. RC4 is a stream cipher where a seed is used as input to the RC4 PRNG which produces an output bit string that is XOR:ed with the plaintext to produce the ciphertext. For WEP the seed to the RC4 PRNG is the key concatenated with the IV. The key is shared between the communicating parties and the IV is transmitted in clear text in each packet. Message integrity is provided using a CRC checksum that is added to the payload and then encrypted together with the rest of the payload. WEP does not protect against replay.

Since the publication of the standard, several shortcomings of WEP have been discovered. Attacks to retrieve the WEP key and to modify the payload have been described. One weakness is the seed derivation. With RC4 it is important that each packet has a different RC4 seed. The RC4 seed in 802.11-1999 is constructed by concatenating the IV and the 40-bit key but the standard did not contain specifications to ensure uniqueness of <key,IV> pairs.

Today, WEP is not considered useful.

## TKIP

The Temporal Key Integrity Protocol (TKIP) is a new protocol that will fix the known problems with WEP. TKIP uses the same ciphering kernel as WEP (RC4) but adds a number of functions:

- 128-bit encryption key.
- 48-bit Initialisation Vector.
- New Message Integrity Code (MIC).
- Initialisation Vector (IV) sequencing rules.
- Per-packet key mixing algorithm that provides a RC4 seed for each packet.
- Active countermeasures.

The purpose of TKIP is to provide a fix for WEP for existing 802.11b products. It is believed that essentially all existing 802.11b products can be software-upgraded with TKIP (all major 802.11 vendors participate in the 802.11i standardisation).

The TKIP MIC was designed with the constraint that it must run on existing 802.11 hardware. It does not offer very strong protection but was considered the best that could be achieved with the majority of legacy hardware. It is based on an algorithm called Michael that is a 64-bit MIC with 20-bit design strength. Details can be found in [802.11i].

The IV sequence is implemented as a monotonically incrementing counter that is unique for each key. This makes sure that each packet is encrypted with a unique <key,IV> pair, i.e. that an IV is not reused for the same key. The receiver shall also use the sequence counter to detect replay

attacks. Since frames may arrive out of order due to traffic-class priority values, a replay window (16 packets) has to be used.

A number of “weak” RC4 keys have been identified for which knowledge of a few number of RC4 seed bits makes it possible to determine the initial RC4 output bits to a non-negligible probability. This makes it easier to cryptanalyze data encrypted under these keys. The per-packet mixing function is designed to defeat weak-key attacks. In WEP, the IV and the key are concatenated and then used as seed to RC4. In TKIP, the cryptographic per-packet mixing function combines the key and the IV into a seed for RC4.

Because the TKIP MIC is relatively weak, TKIP uses countermeasures to compensate for this. If the receiver detects a MIC failure, the current encryption and integrity protection keys shall not be used again. To allow a follow-up by a system administrator the event shall be logged. The rate of MIC failure must also be kept below one per minute, which means that new keys shall not be generated if the last key update due to a MIC failure occurred less than a minute ago. In order to minimize the risk of false alarms, the MIC shall be verified after the CRC, IV and other checks have been performed.

TKIP is an interim solution to support 802.11i on legacy hardware. It is not considered as secure as the AES solution (WRAP) but very much better than WEP.

## WRAP (AES)

The Wireless Robust Authenticated Protocol (WRAP) is the long-term solution and is based on the Advanced Encryption Standard (AES). AES is a block cipher that can be used in different modes of operation. In 802.11i, two modes have been discussed: Offset Codebook (OCB) and Counter-mode with CBC-MAC (CCM). These two modes use AES differently to provide encryption and message integrity. OCB is a mode that provides both encryption and integrity in one run. CCM uses the Counter-mode for encryption and CBC-MAC for integrity. It is currently undecided if both or only one of the modes will be included in the final 802.11i spec. Both modes have been submitted to NIST as proposed block cipher modes.

The AES implementation requires hardware support and the majority of legacy 802.11b products will thus not be able to run WRAP.

# 5 Time plan estimates

The current official 802.11 estimate is that 802.11i will be approved by September 2003. The standard will of course be stable before that and pre-standard products will appear on the market.

In practice the path to a secure 802.11 is a two-step process. The 802.11 industry is not willing to wait for 802.11i to be approved and will therefore issue an interim specification. The industry alliance for 802.11 (WECA) plans to issue this interim spec in the 2nd half of 2002 and it will essentially be a subset of the current 802.11i draft. This specification is supported by major WLAN companies, the same companies are active in 802.11i. WECA performs interoperability tests and certification of 802.11 products and plans to perform interoperability testing of this interim security solution by the end of 2002. The interim solution will probably include TKIP encryption and 802.1X/EAP authentication and key management. The AES solution will probably not be included in the interoperability tests but may be supported by vendors.

The AES solution requires hardware support and pre-standard products will probably be available by the end of 2002 or beginning of 2003.

The EAP-SIM and EAP-AKA specifications are Internet Drafts in late stages. It is expected that they will become RFCs in the second half of 2002.

# References

[802.11-1999] IEEE Standard 802.11, 1999 edition: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications.

[802.11a] IEEE Standard 802.11a, 1999 edition (supplement to 802.11-1999): High-speed Physical Layer in the 5 GHz Band.

[802.11b] IEEE Standard 802.11b, 1999 edition (supplement to 802.11-1999): Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

[802.11i] IEEE Draft Standard 802.11i, D2.1 (March 2002): Specification for Enhanced Security.

[802.1X] IEEE Standard 802.1X (2001): Port-Based Network Access Control.

[EAP] RFC 2284: PPP Extensible Authentication Protocol.

[EAP-SIM] Internet Draft: EAP SIM Authentication (draft-haverinen-pppext-eap-sim-03.txt).

[EAP-AKA] Internet Draft: EAP AKA Authentication (draft-arkko-pppext-eap-aka-03.txt).

[EAP-TLS] RFC 2716: PPP EAP TLS Authentication Protocol.