**IEEE P802.15**

**Wireless Personal Area Networks**

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| Title | Change Proposal for Secure Authenticating Ranging using LRP UWB PHY |
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| Abstract | [Proposal for Secure Authenticated Ranging based on LRP UWB PHY 802.15.4z] |
| Purpose | [Propose elements of Secure Authenticated Ranging PHY/MAC descriptions] |
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6.17 Secure authenticated ranging

Secure authenticated ranging is a round-trip-time ranging using a challenge-response one-way authentication and/or mutual authentication mechanism.

Secure authenticated ranging uses the MAC sublayer providing the security services defined in Clause 9. Secure ranging is provably secure in LRP UWB Base and Dual-Frequency Modes as defined in Clause 19. Secure authenticated ranging provides the highest security guarantees as defined by the Security Levels of the MAC sublayer in Table 9-6.

Secure authenticated ranging uses data frames as defined in 7.3.2. When specified in this clause as secured, data frames used for secure authenticated ranging are secured at security level 1, 2 or 3.

A device performing secure authenticated ranging with one-way authentication or mutual authentication shall have the macSecurityEnabled set to TRUE and shall be disabled otherwise. The secure ranging devices shall provide cryptographic transformations on incoming and outgoing frames using information in the PIB attributes associated with security services defined in Clause 9.

**[Comment<1>:** Is there need DefineIEto indicate one-way vs. mutual authentication**]**

**6.17.1 Secure ranging with one-way authentication**

This subclause describes the two-way message exchange based on AES CCM\* security services in 9.1 used to achieve secure ranging with one-way authentication.



Figure 1- Secure ranging with one-way authentication

**6.17.1.1 VChallenge**

VChallenge is a fresh random number of 32, 64 or 128 bits corresponding to the chosen Security Level. The generation mechanism is outside the scope of this standard.

|  |  |
| --- | --- |
| **VChallenge** | **Length (bits)** |
| VChallenge32 | 32 |
| VChallenge64 | 64 |
| VChallenge128 | 128 |

The Security Level shall be set to 0 in the Security Control field of the Auxiliary Security Header. This indicates that VChallenge is neither authenticated, nor encrypted data, i.e., no CCM\* transformation is performed on the VChallenge.

**6.17.1.2 PResponse**

PResponse is a secured frame which contains the received VChallenge and its MIC (Message Integrity Code) computed using the security service of data authenticity as defined in Table 9-4. Table X defines the *a*data to be used for the CCM\* authentication transformation to compute the *c* data. VChallenge shall be the Unsecured Private Payload field defined in Table 9.3.

|  |  |  |  |
| --- | --- | --- | --- |
| Security level | *a* data | *m* data | *c* data |
| 0 | Not applicable | Not applicable | Not applicable |
| 1 | MHR || VChallenge32 | None | MIC-32 |
| 2 | MHR || VChallenge64 | None | MIC-64 |
| 3 | MHR || VChallenge128 | None | MIC-128 |

NOTE—The MHR contains the Auxiliary Security Header field, as defined in 7.2

**6.17.2 Secure ranging with mutual authentication**

This subclause describes the three-way message exchange based on AES CCM\* security services in 9.1 in order to achieve secure ranging with mutual authentication.



Figure 2 Secure ranging with mutual authentication

**6.17.2.1 VChallenge**

VChallenge is a fresh random number of 32, 64 or 128 bits corresponding to the chosen Security Level. The generation mechanism is outside the scope of this standard.

**6.17.2.2 PResponseChallenge**

PResponseChallenge is a secured frame which contains the received VChallenge from the Verifier device and a freshly generated random number PChallenge by the Prover device and their MIC computed using the security service of data authenticity as defined in Table 9-4.

PChallenge is a fresh random number of 32, 64 or 128 bits generated by the Prover device according to the chosen Security Level.

Table X defines the *a*data to be used for the CCM\* authentication transformation to compute the *c* data of the PResponseChallenge message. The VChallenge and PChallenge shall be the Unsecured Private Payload field defined in Table 9.3.

|  |  |  |  |
| --- | --- | --- | --- |
| Security level | *a* data | *m* data | *c* data |
| 0 | Not applicable | Not applicable | Not applicable |
| 1 | MHR || PChallenge32 || VChallenge32 | None | MIC-32 |
| 2 | MHR || PChallenge64 || VChallenge64 | None | MIC-64 |
| 3 | MHR || PChallenge128 || VChallenge128 | None | MIC-128 |

NOTE—The MHR contains the Auxiliary Security Header field, as defined in 7.2

**6.17.2.4 VResponse**

VResponse is a secured frame which contains the received VChallenge and PChallenge from the Prover device and their MIC computed using the security service of data authenticity as defined in Table 9-4.

Table X defines the *a*data to be used for the CCM\* transformation to compute the *c* data of the VResponse. The VChallenge and PChallenge shall be the Unsecured Private Payload field defined in Table 9.3.

|  |  |  |  |
| --- | --- | --- | --- |
| Security level | *a* data | *m* data | *c* data |
| 0 | Not applicable | Not applicable | Not applicable |
| 1 | MHR || VChallenge32 || PChallenge32  | None | MIC-32 |
| 2 | MHR || VChallenge64 || PChallenge64 | None | MIC-64 |
| 3 | MHR || VChallenge128 || PChallenge128  | None | MIC-128 |

NOTE—The MHR contains the Auxiliary Security Header field, as defined in 7.2

**6.17.3 Secure ranging with tolerance of bit errors**

This subclause describes the two-way message exchange for secure ranging which allows tolerance of bit errors during the ranging.

This type of secure ranging assumes that VChallenge and PChallenge are exchanged between the Verifier device and Prover device before the secure ranging takes place or after the secure ranging has taken place.



Knowledge of VChallenge and PChallenge by the Verifier device and Prover device prior to the two-way ranging or after the two-way ranging allows the upper application layer to verify the validity of the VChallenge and PChallenge even if bit errors have occurred during the transmission. Annex G provides informative information on the sizes of VChallenge and PChallenge in order to achieve the desired Security Level.

VChallenge and PChallenge can be securely exchanged between the Verifier device and Prover device by using the security services in Clause 9, out-of-band (OOB) communication or other means by the upper application layers.

**6.17.3.1 VChallenge**

VChallenge is a fresh random number of a given amount of bits. Annex G provides examples on how to compute the amount of bits to be used based on the required Security Level. The generation mechanism is outside the scope of this standard.

**6.17.3.2 PChallenge**

PChallenge is a fresh random number of a given amount of bits. Annex G provides examples on how to compute the amount of bits to be used based on the required Security Level. The generation mechanism is outside the scope of this standard.

**6.17.4 Distance commitment**

Distance commitment ensures that the data of the PSDU carrying the nonce and MIC of the MAC payload is decoded at the measured distance by the earliest path(s). This is essential to secure authenticated ranging and provable security as defined in Annex G.

Figure 3 illustrate the distance commitment. Channel state information (channel impulse response) is available after the SHR. The earliest path(s) are detected from the channel state information. During reception of PSDU only the “earliest path(s)” portion of the received signal shall be used for data decoding.

**[Comment<2>:** Provide more precise definition of “earliest path(s)” in order to ensure strict security guarantees between different chip vendors. This would need to be formulated in Annex G as normative.**]**



Figure 3 Distance commitment

**6.17.5 Protocol verification**

Verification for success or failure is performed by the Verifier in the one-way authentication and by both the Verifier and the Prover in the mutual authentication.

The verification procedure of secure authenticated ranging consists of bit-wise matching the received nonces and computed MIC.

**[Comment<3>:** Include a section on the type of shared keys to be used. Especially, mandate the use of only link keys (i.e., pair-wise shared keys) between devices and not group keys. Keys shared by a group of devices can be subject to insider attacks, i.e., the attacker can impersonate as an innocent device, associate with the group, thereby obtain the group key for launching the forgery attacks. Can be stated as requirement when using Secure authenticated ranging, or as a strong recommendation TBD]

Annex G (informative) Security guarantees of secure authenticated ranging

**[Comment<4>:** Some aspects need to be normative]

**Protocols/Logical Layer:**

The presented secure ranging protocols are natural extensions of one-way and mutual authentication protocols. However, since the analysis of ranging protocols includes notions of time and distance, proving their security requires being able to reason about such notions. [TISSEC2011] presents a formal model for the analysis of such protocols. In particular, it describes (Section 3) and formally proves the security of a signature-based “authenticated ranging protocol” (Section 5.1). Secure ranging with one-way authentication described in this standard (6.17.1) aims to achieve the same security properties as authenticated ranging, namely, authentication and prevention of any distance reduction attacks. Namely, assuming mutually trusted parties, their measured distance should constitute an upper bound on their actual distance. The only difference between the two protocols is that for message authentication, the protocol in this standard uses a Message Integrity Code (based on the shared secret keys), and includes principal names in the messages, as opposed to the protocol in [TISSEC2011] which relies on public-key signatures. Given this, the formal proof can be easily extended to cover the protocol described in the standard and the results naturally carry over.

The proofs in [TISSEC2011] are done in the symbolic model, assuming that the cryptographic primitives (i.e., signature and MIC) are ideal. This means that the nonces, signatures and MICs are assumed to be unguessable and unforgeable. The protocols are therefore proven secure under that assumption. Assuming that the signature and MIC cannot be forged by the attacker (without the knowledge of the key), the remaining ways for the attacker to violate the security guarantees of these protocols are by guessing the nonces/MICs or by collecting all nonce/MIC pairs. The guessing probabilities of such an attack, for different nonce and MIC sizes are given in Table 1. If the nonce is large enough or if the system rate limits the interactions, then the attacker cannot collect all or most nonce and MIC pairs. The security reasoning for the secure ranging with mutual authentication follows the same reasoning. Namely, this protocol simply combines two one-way secure ranging protocols.

Assuming that the devices can support public key signatures, the proposed protocols can be simply used with public key signatures, replacing MICs. This design is proven in [TISSEC2011].

**Physical Layer:**

In [ESAS2006] the authors argued that, if implemented naively, secure ranging protocols will be vulnerable to physical layer attacks. Most prominent of these attacks is the early detect / late commit attack that exploits long symbols and allows the attacker to cheat on the distance up to the symbol length even if the logical layer protocol is secure.
One safe way to prevent such attacks is to use short symbols (only few ns long). In that case, the attacker can cheat up to few nanoseconds. For an LRP UWB system this means that the attacker’s ability to cheat will depend on the pulse duration and therefore be proportional to the bandwidth of LRP UWB (400MHz – 2.14GHz). The corresponding range of the maximum distance decrease for different bandwidth is given in Table 1. For a bandwidth of 2.14 GHz the maximum distance decrease is 14 cm whereas for 400MHz it is 75cm. These are worst-case numbers. In all realistic scenarios, where the attacker has non-zero detection and non-zero processing time, the maximum distance decrease will be lower.

The secure ranging design in described in 6.17.3 follows the *distance commitment* design that was first described in [WISEC15]. A distance commitment allows a sender to claim to be in a certain distance (by the transmission time of the preamble), which he has to prove later by supplying the correct secret at the correct time on the channel.
The exact transmission timing of the preamble tells the receiver when to sample the channel to extract symbols to demodulate. In this sense, it is a commitment by the sender to send the data at exactly those times, as defined by the physical-layer protocol. The receiver will start sampling the channel for each symbol with timing as defined by the arrival of the preamble. In other words, the insecure distance measurement based only on the preamble simplifies and enables the secure distance measurement by providing correct synchronization. If the preamble is sent earlier by the attacker, the receiver will expect the data pulses earlier as well and thus start the sampling intervals earlier. If the attacker cannot provide correct data pulses in these earlier sampling intervals (e.g., because the prover did not send them yet), the receiver will demodulate random data. Even if he advances the preamble, the attacker therefore cannot cheat on the distance since it cannot provide the correct data (nonce and MIC) before they are sent by V or P.

Table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Security Level | Nonce length (bits) | Probability of guessing the nonce | Forging of MIC(as per AES CCM\* in Clause 9) | Worst Case Maximum Distance Decrease (1) |
| 0 | Not applicable | Not applicable | Not applicable | Not applicable |
| 1 | 32 | 1/2^32 (2.32e-10) | MIC-32 | 14 cm – 75 cm |
| 2 | 64 | 1/2^64 (5.42e-20) | MIC-64 | 14 cm – 75 cm |
| 3 | 128 | 1/2^128 (2.93e-39)  | MIC-128 | 14 cm – 75 cm |

*Footnote 1: Worst Case Maximum Distance Decrease for strongest theoretical attacker with zero detection time and zero processing time is proportional to the bandwidth of LRP UWB ranging from 400 MHz to 2.14 GHz*

**Comment<5>:**  Worst Case Maximum Distance Decrease depends on the window. We have to specify window for demodulation of the cryptographic data bits based on signal bandwidth e.g., ( mask of the pulse – 400 MHz at -10 dB bandwidth). This would need to be normative in the case of secure authenticated ranging! Otherwise the system may not be secure. Restate as normative requirement.

**Security Levels in case of secure ranging with tolerance of bit errors**

Table 2 shows recommended length of the challenge and response nonce in case of that the higher security application layer tolerates 10% bit errors.

Table 2.

|  |  |  |  |
| --- | --- | --- | --- |
| Security Level | Recommended Nonce length (bits) | Probability of guessing the nonce in case of 10% bit errors | Worst Case Maximum Distance Decrease (1) |
| 0 | Not applicable | Not applicable | Not applicable |
| 1 | 60 | > 1/2^32 (2.32e-10) | 14 cm – 75 cm |
| 2 | 120 | > 1/2^64 (5.42e-20) | 14 cm – 75 cm |
| 3 | 230 | >1/2^128 (2.93e-39)  | 14 cm – 75 cm |

[TISSEC2011] David A. Basin, Srdjan Capkun, Patrick Schaller, Benedikt Schmidt, Formal Reasoning about Physical Properties of Security Protocols. ACM Trans. Inf. Syst. Secur. 14(2): 16:1-16:28 (2011)

[WISEC15] Nils Ole Tippenhauer, Heinrich Luecken, Marc Kuhn and Srdjan Capkun, UWB Rapid-Bit-Exchange System for Distance Bounding, In Proceedings of the ACM Conference on Security and Privacy in Wireless and Mobile Networks (WiSec), 2015

[ESAS2006] Jolyon Clulow, Gerhard P. Hancke, Markus G.Kuhn, and Tyler Moore. So near and yet so far: Distance-bounding attacks in wireless networks. In Proceedings of the European Workshop on Security and Privacy in Ad-hoc and Sensor Networks (ESAS), 2006.