Bluetooth Security

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Outline

- Introduction
- Threats in Computer Networks
- BT Security Architecture
- BT Security Philosophy
- Key Types: Link Keys
- Algorithms
- Key Management Protocol
- BT Security Weaknesses
- Recommendations

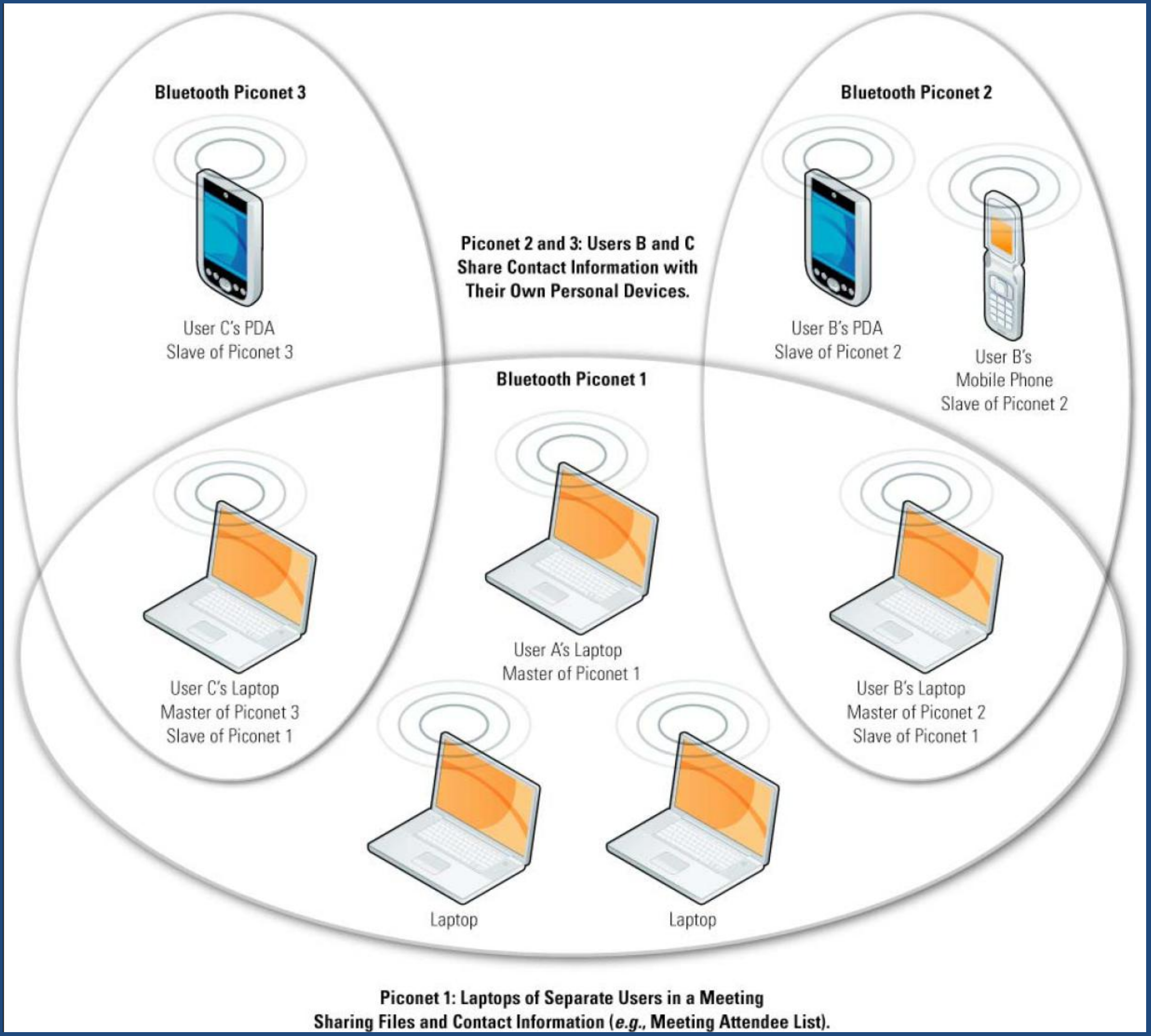
Introduction

- Bluetooth is developed by SIG in 1998.
- Always-on, low power, low cost, short range, wireless technology for devices.
- Wireless Personal Area Network (WPAN) is established.
- Cable Replacement and Ease of Sharing.

Connectivity

- Ad-Hoc Network by forming a star shaped cluster called Piconet (Master and Slaves).
- Using a Bluetooth Access Point (BT-AP).
- Up to a maximum of Seven active slave and 255 inactive ones in a connection.
- Scatternet can be formed by sharing of common slaves or different roles of one device in two piconets.

Connectivity



Technical Specifications

- Devices can exchange data up to 723 Kbps.
- Operates in the unlicensed radio range of 2.45 GHz.
- The range of a BT device is divided into one of three classes according to the power level:
  - Class 1: High Power of 100mW and a range of 100 meters.
  - Class 2: Medium Power of 2.5mW and a range of 10 meters.
  - Class 3: Low Power of 1mW and a range of 0.1 – 10 meters.

Link Manager Protocol (LMP)

- Handling the connection, authentication, authorization, encryption, and key management between devices.
- Used by each device to keep track of connected devices.
- Communicate together via PDU.
- New Connections: (1) Inquiry (2) Page
- Pairing start afterwards, opposite device is (trusted).

Threats in Computer Networks

- **Disclosure:** a threat against the confidentiality of the information.
- **Integrity:** a threat that invloves an unathorized change of the information.
- **Denial of Service (DoS):** a threat against the availability of the system.

Bluetooth Security Architecture
Generic Access Profile (GAP)

- Supports 3 Security Services:
  - Authentication
  - Authorization
  - Confidentiality
- Supports 3 Security Modes
- Supports 2 Security Levels for Devices and 3 Security Levels for Services
- Keys Generation, Exchange, Random Numbers, and etc…

Security Services

- Authentication
  - Verifying the identiy of communicaing devices. It is commonly done through the use of PIN.
- Authorization
  - Allowing the control of resources, checking whether a device is allowed to use a service or not.
- Confidentiality (Encryption)
  - Protecting the information exchange in such a way that no one can understand it except the designated recipient.

Security Modes

- Mode 1: Non-secure
  No security measures. No authentication, authorization, or encryption. Both devices and connection are vulnerable to attack.
- Mode 2: Service-level enforced security
  Flexibility in security measures. ACL link can be established in a non secure manner. Security procedures are enforced when there is a service request.
- Mode 3: Link-level enforced security
  Strict in security measures. Security measures are initiated when the ACL link is being established.

Security Modes

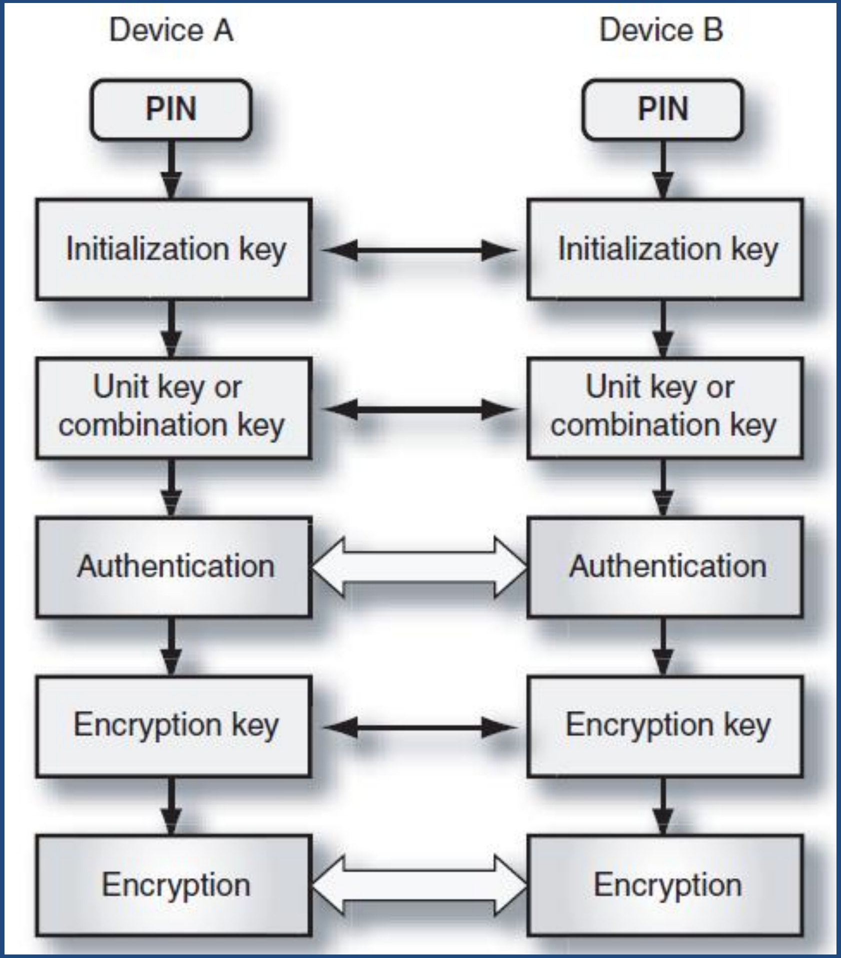
- The Difference between Security Modes 2 and 3.

- In Mode 3, three phases are defined:
  - Initialization phase: Construction of trust and exchange of keys.
  - Meeting phase: Proof of authenticity.
  - Communication phase: Secure data exchange.

Security Levels

- Devices
  - Trusted
  - Untrusted
- Services
  - Accessible to all devices. No need for a PIN or a Password.
  - Authentication only. Need for a Password.
  - Authentication and authorization. Need for a Password followed by an authorization procedure.

Philosophy of Bluetooth Security

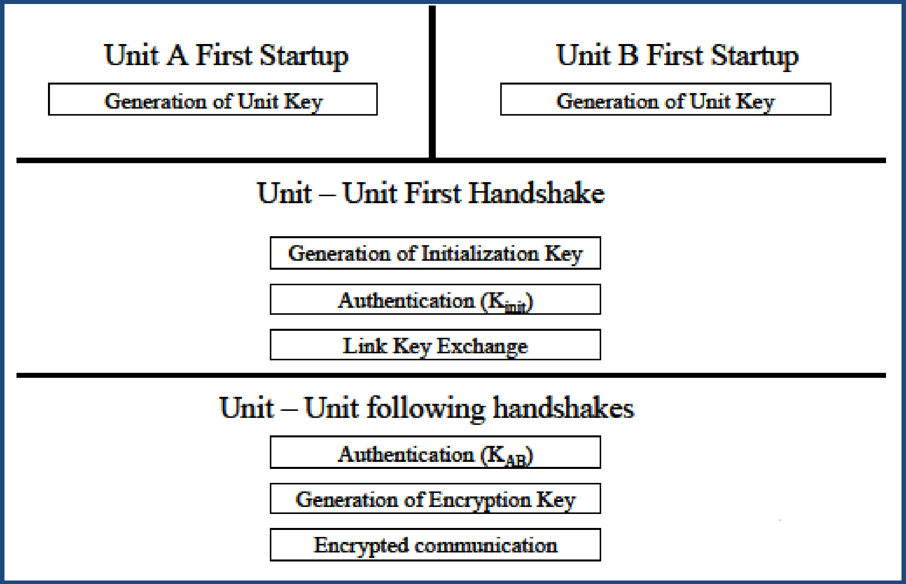


- Chain of events: (Briefly)

1) Each device calculate its own Unit Key (K_A and K_B).
2) When they meet, devices begin with PIN.
3) From PIN, derive Kinit.
4) After K_{init}, Pairing Process occurs.
5) Link Key Exchange using K_{init} : K_A or K_B, or a more secured one, K_{AB}
6) K_A or K_{AB} are used in Authetication and Encryption.

Bluetooth Security Overview

- Unit A First Startup
- Unit B First Startup
- Unit - Unit First Handshake
- Unit - Unit following Handshakes



Security Entities

Entity	Description	Length (Bits)	Status
PIN	Personal identification number	8, 16, . . . , 128	Private
BD_ADDR	Bluetooth device address	48	Public
K_{init}	Initialization key	128	Private
K_A	Unit key	128	Private
K_{AB}	Combination key	128	Private
K_{master}	Master key	128	Private
K_C	Encryption key	8, 16, . . . , 128	Private
IN_RAND	Random number for generating K_{init}	128	Public
LK_RAND	Random number for generating K_{AB}	128	Private
AU_RAND	Random number for authentication	128	Public
EN_RAND	Random number for generating K_C	128	Public
SRES	Authentication result	32	Public
ACO	Authenticated ciphering offset	96	Private

RAND

Security Entities

- Personal Identification Number (PIN) – 8, 16, … ,128 bits – Private. Fixed, so entered to the device wishing to connect or entered to both devices at the beginning.
- Bluetooth Device Address (BD_ADDR) – 48 bits – Public. Unique for each device and identified by IEEE.
- Random Number (RAND) – 128 bits – Public. Every Bluetooth device is equipped with a random number generator that can create as 128-bit random binary number on demand.
- Encryption Key (K_c) – 8, 16, … ,128 bits – Private. Used to change plain text into cipher and vice versa.

Key Types: Link Keys

- All security transactions between two or more parties are handled by the link key.
- Regardless of its type, a link key is always 128 bits long.
- They can be either initialization (K_{init}), semi-permanent (K_A or K_{AB}), temporary (K_{master}) keys.

Key Types: Link Keys

- Initialization Key (K_{init}): created once from PIN when two devices with no prior agreement or previous communication meet. Discarded afterwards.
- Unit Key (K_A): created once for a device that has low memory resources.
- Combination Key (K_{AB}): created from the combination of inputs provided by Devices A and B.
- Master Key (K_{master}): created for the purpose of broadcasting packets to multiple slaves.

Algorithms

- They are all based on Secure and Fast Encryption Routine (SAFER+). A Symmetric Block Cipher operating on a fixed length groups of bits (blocks).
- Keys Generation and Authentication
  - E22 for deriving K_{init} as initialization key.
  - E21 for deriving K_A and K_{AB} as link keys.
  - E1 for applying authentication procedures.
  - E3 for deriving K_c as encryption key.
- Encryption
  - E0 for Cipher Stream generation.

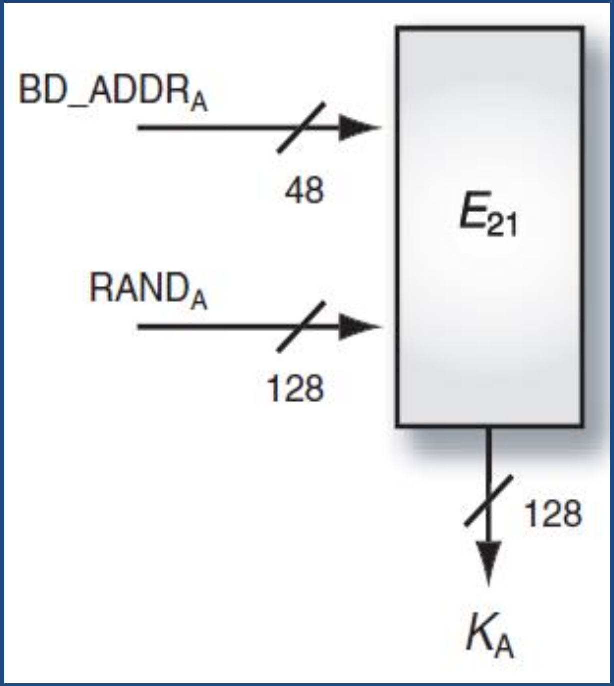
Key Management Protocol

- IN_RAND: For Initialization Key
- $RAND_A$: For Unit Key
- LK_RAND_A and LK_RAND_B: For Combination Key

Link Key Name	Symbol	Formula
Initialization key	K_{init}	$E_{22}(PIN', L', IN\_RAND)$
Unit key	K_A	$E_{21}(BD\_ADDR_A, RAND_A)$
Combination key	K_{AB}	$E_{21}(BD\_ADDR_A, LK\_RAND_A) \oplus E_{21}(BD\_ADDR_B, LK\_RAND_B)$
Master key	K_{master}	$E_{22}(RAND1, RAND2, 16)$

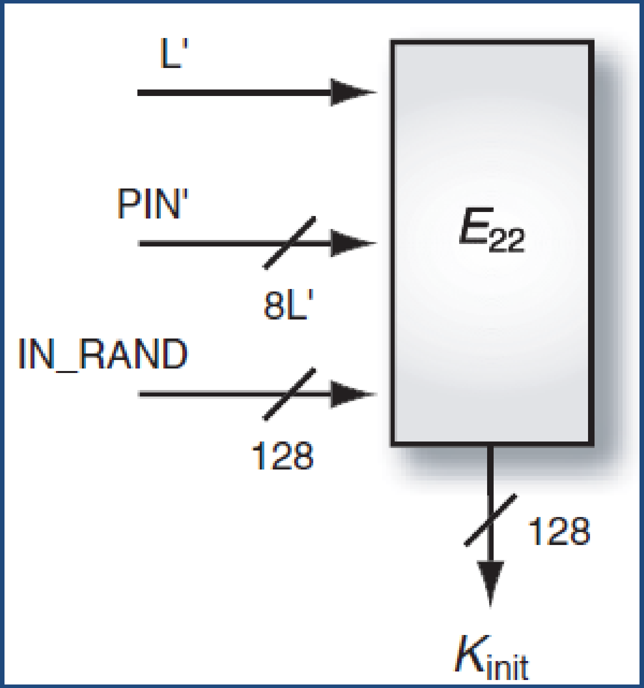
(1) Unit Key

- For Device A or B, K_A or K_B is created:
  - BD_ADDR_A or BD_ADDR_B
  - $RAND_A$ or $RAND_B$

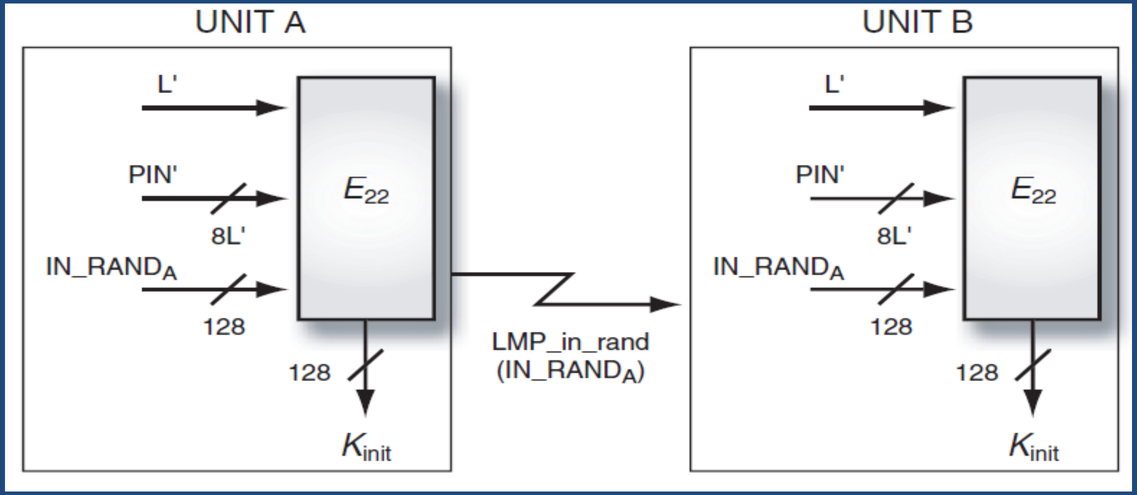


(2a) Initialization Key
First Handshake

- Used to protect the generation and transfer of other keys that are more secure.
- Used in the following steps as temporary link key.
- At the beginning, calculated by the initiator and then by the responder (Pairing Process).
- L': Length of PIN, PIN', and IN_RAND: Random Number



(2b) Pairing Process First Handshake



- Starts after the creation of K_{init}.
- Essential when two devices have never met before via Bluetooth.
- Same Pin is used in both devices.
- IN_RAND_A of Device A is transferred to Device B, so same K_{init} can be calculated. Pairing is successful.

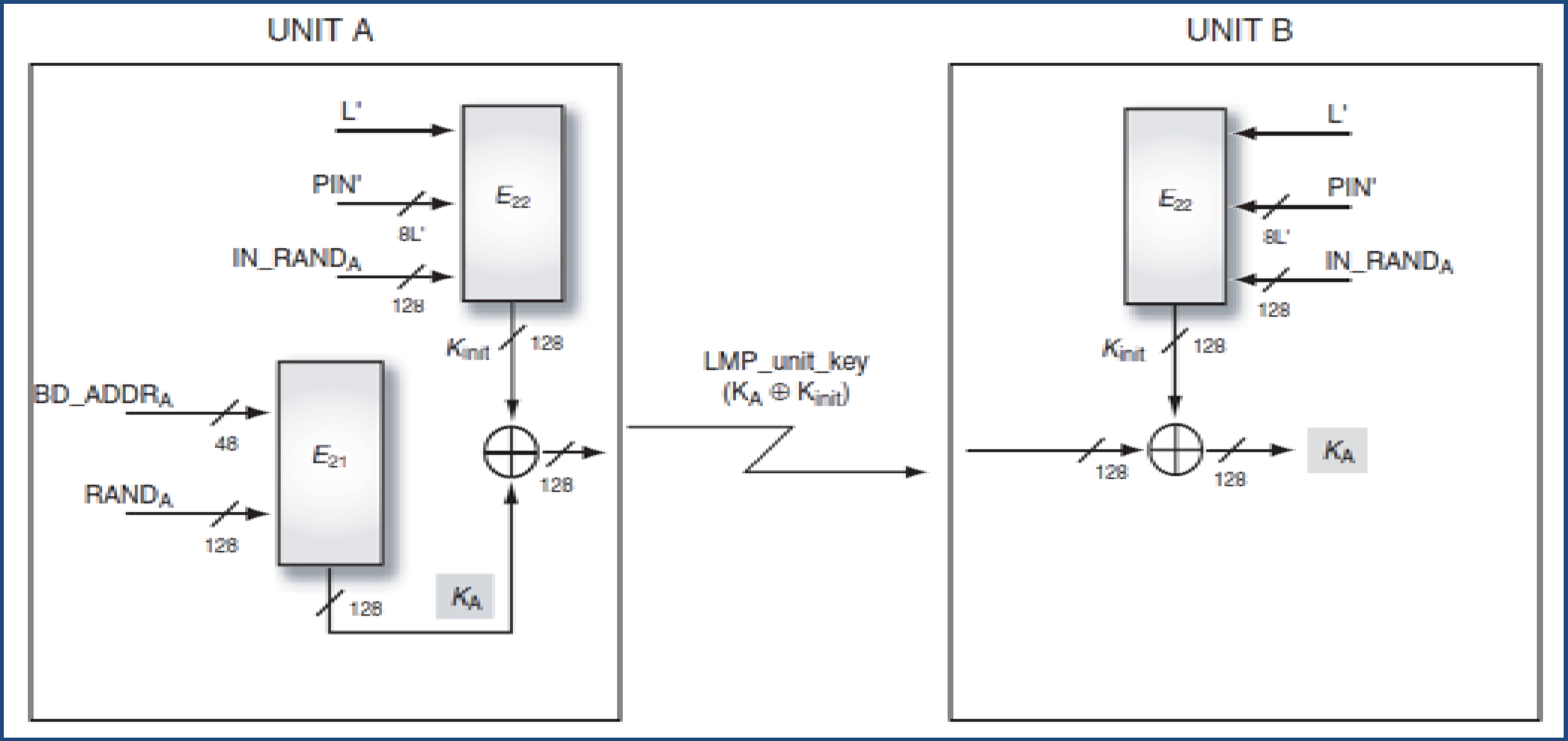
(3) Link Key Generation

- Two Scenarios are possible:
  - Link Key is a Unit Key (i.e. K_A). Obviously, it is already generated in Device A. So, it has to be transferred securely to Device B.
  - Link Key is a Combination Key (i.e. K_{AB}). So, a different procedure takes place.
  - Using a Combination Key as a link key is much more secure than a Unit Key (Why?).

(3) Link Key Generation -1-
$K_A = K_{link}$

- If Device A is with limited memory, then use its Unit Key (K_A) as the Link Key.
- How to transfer (K_A) , securely, to Device B:
  - Encrypt the Unit Key (K_A) with the Initialization Key (K_{init}) by XORing them together.
  - In Device B, decrypt the Unit Key by the Initialization Key.

(3) Link Key Generation -2-
$K_A = K_{link}$



- Therefore, $K_A = K_{link}$.

(3) Link Key Generation -1- $K_{AB} = K_{link}$

- If memory resources is *not* an issue. Then, it is better to generate a more sophisticated link key by *combining* K_A and K_B together.

$$K_{AB} = K_A \oplus K_B$$

- Fact: K_{AB} should be available at both devices. Each device can calculate its own unit key and should calculate the unit key of the other device. Each device knows the Bluetooth Device Address (BD_ADDR) of the other device (Public).
- Needed: Each device sends its own Random Number (LK_RAND), encrypted ($\oplus$) by K_{init}, to the other device.

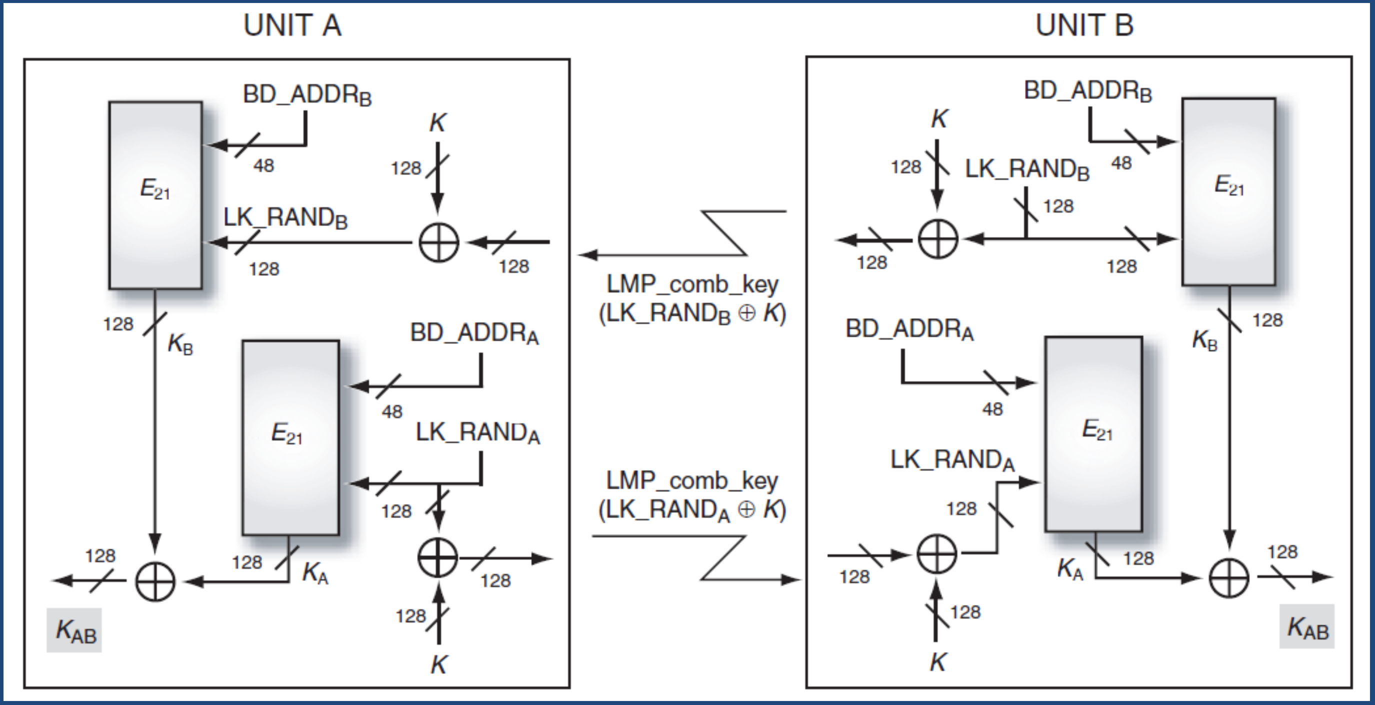
(3) Link Key Generation -2- $K_{AB} = K_{link}$

- Therefore, A sends ($LK\_RAND_A \oplus K_{init}$) to B, and B sends ($LK\_RAND_B \oplus K_{init}$) to A. Each unit can decode the other's LK_RAND by the following operation:

$$(LK\_RAND \oplus K_{init}) \oplus K_{init} = LK\_RAND$$

allowing the generation of the Unit Key of each device on the other's side.

(3) Link Key Generation -3- $K_{AB} = K_{link}$



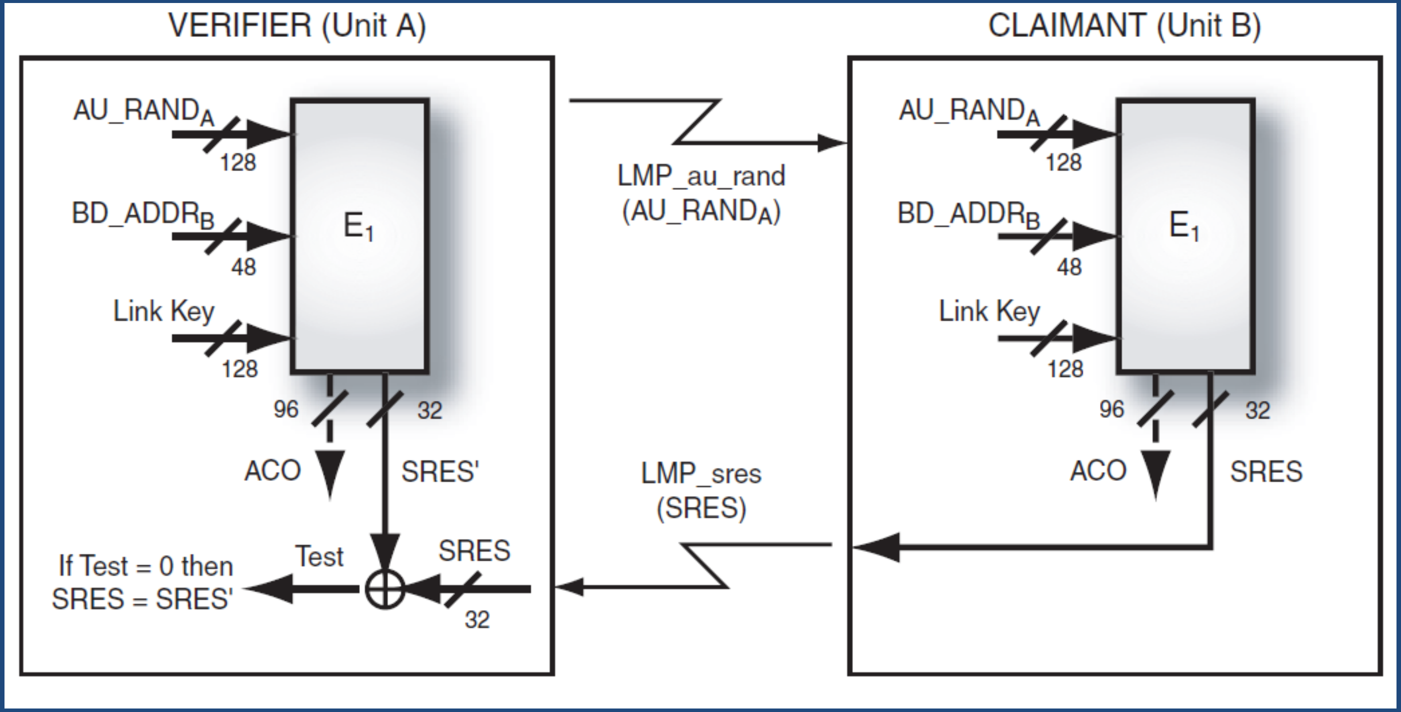
- As explained, $K_{AB} = K_{link}$. Note that LK_RAND is the only Private Random Number in BT.

(4) Authentication
Challenge – Response action

- Two parties are involved, the verifier and the claimer.
- The verifier challenges the claimer and gets a response from it.
- Challenge: 128-bit Random Number (AU_RAND_A) generated by Verifier.
- The following operation, which is based on SAFER+, is performed at the verifier and afterwards at the claimer:

$$E1(BD\_ADDR_B, AU\_RAND_A, K_{link})$$

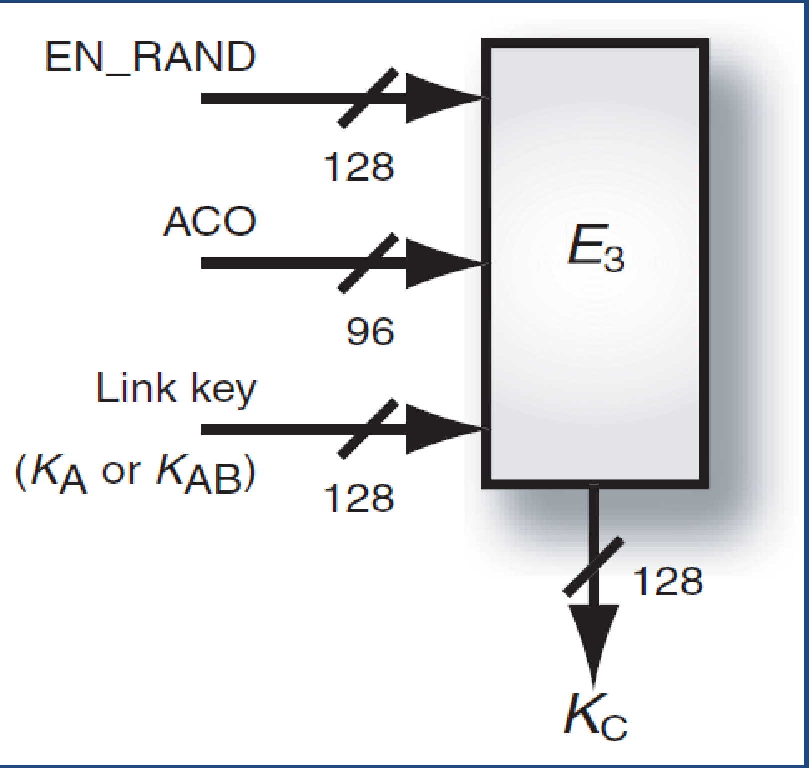
Challenge – Response action



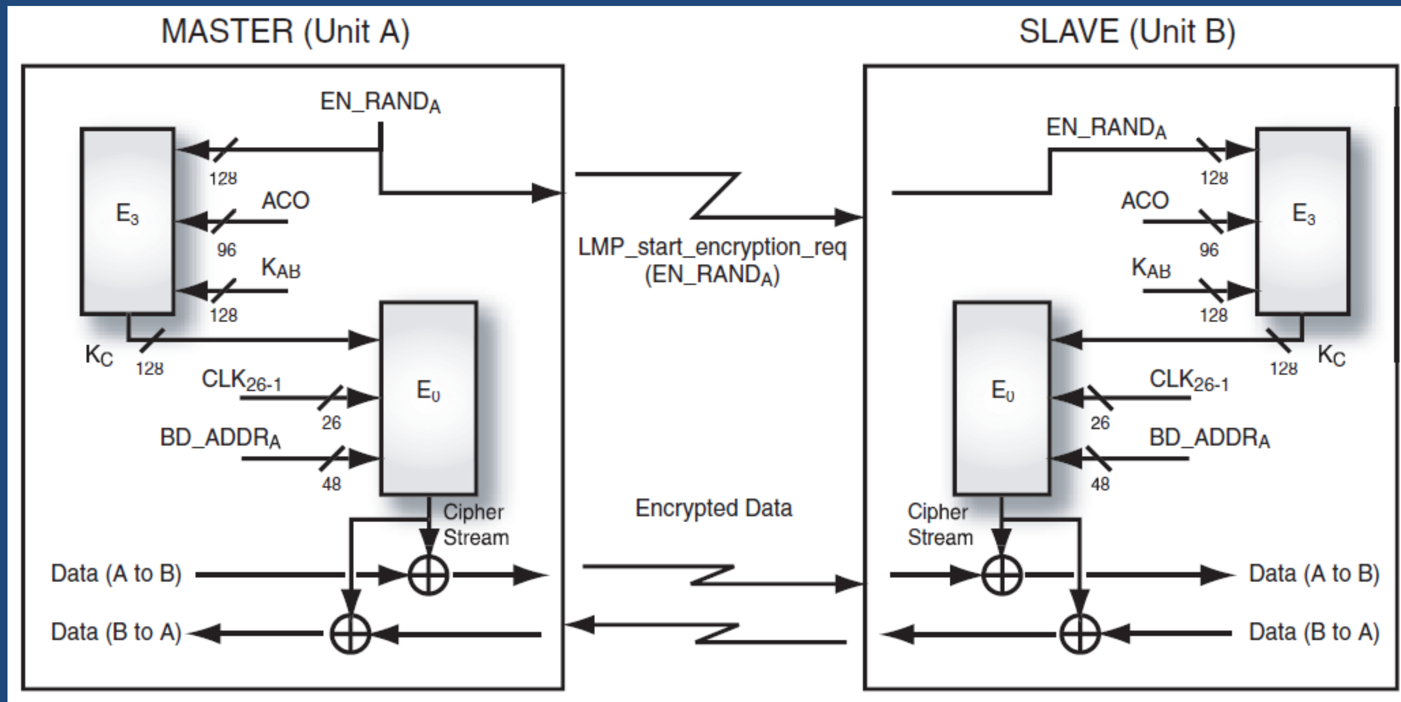
- Output from A is SRES' and Response from B is SRES.
- If SRES' = SRES, then authentication is successful.

(5) Encryption Key (K_c)

- For Device A or B, K_c is created as a first step:
  - Public EN_RAND generated by A and then sent to B.
  - Current Link Key (K_A or K_{AB}).
  - 96-bit Authenticated Ciphering Offset (ACO).



(5) Cipher Stream



- As a second step, a Cipher Stream is generated at both sides:
  - Encryption Key (K_c)
  - Master Clock (CLK)
  - BD_ADDR$_A$

Bluetooth Security Weaknesses

- Problems with E0 and E1
  - Based on SAFER+ with security weaknesses, in addition to a slow performance.
- Unit Key
  - K_A is sent to B ($K_A \oplus K_{init}$) as K_{link}. Now, B has K_A. B can claim A's identity in a communication with C.

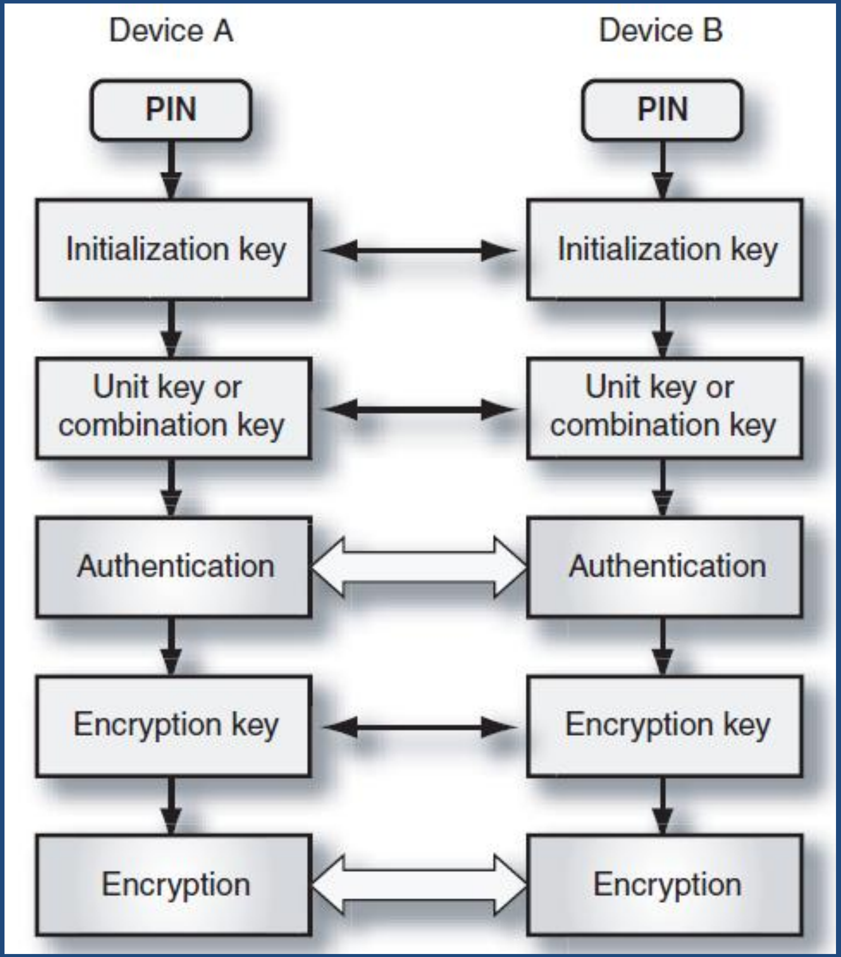
Bluetooth Security Weaknesses

- PIN and Initialization Key
  - Recall, Generation of Initialization Key. Everything is Public except PIN. Brute Force attack is possible.
  - By Knowing PIN, K_{init} is no longer a secret.
  - By Knowing K_{init}, several processes will be affected.
    - Combination Key Generation
    - Mutual Authentication

Recommendations

- Use long and sufficiently random PINs. People prefer the default value (i.e. 0000). Some of them use weak values (1234, 5555, ….). Brute Force attack is possible.
- Never use a Unit Key (K_A) as a Link Key (K_{link}). Better to use a Combination Key (K_{AB}).
- Use Security Modes 2 and 3. Turn on Authentication, Authorization, and Encryption functionalities.

Wrap Up !


Device A
Device B
PIN
PIN
Initialization key
Initialization key
Unit key or combination key
Unit key or combination key
Authentication
Authentication
Encryption key
Encryption key
Encryption
Encryption

Thank You ☺