IV index

Application note

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1. Introduction

This document provides installers and designers of Bluetooth mesh networks with the following information:

- How the Initialization Vector Index (IV index) works.
- Why issues may occur in the network.
- Troubleshooting steps to resolve these issues.

The IV index is a 32-bit value that is included in every message sent using the Bluetooth mesh protocol. It is a mandatory part of the Bluetooth mesh specification and its role is to make sure that communication between devices in the network is secure.

In the Silvair implementation, the IV index can be stored in the device itself, in the Silvair cloud, and in the Silvair mobile app. The mobile app reads the IV index as it connects to a device. Only the highest IV index seen in the network by the mobile app so far is stored in the cloud.

2. How the IV index works

Each device in Bluetooth Mesh uses a sequence number and the IV index to encrypt/decrypt messages.

The sequence number is a 24-bit value, which means that a device can send 16,777,216 messages before the sequence number reaches its limit.

To extend the longevity and to ensure that each message in the mesh network can still be secured, the sequence number is combined with a 32-bit IV index. This approach significantly extends the number of messages that a device can send before running out of combinations.

Each message sent over the mesh is checked by the receiving device to make sure that these two conditions are met:

- The sequence number is higher than the last one received from this device.
- The IV index matches.

If either of these conditions is not met then the message is ignored. This unique combination of sequence number and IV index for each message ensures the security of transmissions throughout the entire lifespan of the mesh network.

For more detail on how the sequence number and IV index are used to manage security in a Bluetooth mesh network, see the Bluetooth mesh specification.

2.1 Setting the initial IV index and sequence number

When the first device is added to a network, it receives an IV index of 0 from the Silvair cloud and it starts with a sequence number of 0.

2.2 Updating the IV index

There are three mechanisms by which the IV index can be updated.

2.2.1 IV Index Update procedure

When the sequence number approaches the highest value (16,777,216) the device increases its IV index by 1 and resets the sequence number. It also sends a message to the rest of the devices in the network that they also need to increase their IV index (regardless of their current sequence number[1]). In this way, the IV index always has the same value throughout the network or is in the process of being unified. This is the "IV Index Update procedure" which is described in the Bluetooth mesh specification.

Each device can also start the IV Index Update procedure if it senses that it or one of its neighbors is approaching the sequence number limit (see the Bluetooth mesh specification for more details).

> The Bluetooth mesh specification does not allow the IV Index Update procedure to occur more frequently than once every 192 hours (8 days).

2.2.2 IV Index Recovery procedure

If a device is power cycled, it will, on power up, listen for a brief period of time for a higher IV index in the network. If it receives a higher IV index from another device or the mobile app within this period, it will adopt it. This is the "IV Index Recovery procedure" and it occurs on each device individually.

> For devices with firmware version earlier than 2.30 and a lower IV index than other devices in the network, the IV index must be updated by reprovisioning or power cycling.

Starting from firmware version 2.30, each device will perform the "IV Index Recovery procedure" every 192 hours, removing the need for reprovisioning or power cycling.

2.2.3 Reprovisioning

By removing the device from the network and adding it again, the IV index will be set to the value recorded in the cloud. This value represents the highest IV index seen by the app for this network so far which is made available via the mobile app.

2.3 IV index issues

Problems will occur in cases where some devices are not in range of others in the network, that is, if the network has 'islands'. An island may be a single device, a group of devices in an area[2], or an entire area, each functioning independently in the network. In this case, the "IV Index Update procedure" will occur separately for each island and different IV indexes will arise in one network. This will cause various problems, most commonly when adding new devices and updating firmware.

The IV index in each island cannot be tracked remotely.

[1] Not all devices transmit at the same rate, so some will reach the sequence number limit before others.
[2] By 'area' we mean a network area as defined in the Silvair Commissioning tool, not an area in physical space.

3. Troubleshooting

3.1 Prerequisites

Go to your App Store account to make sure that you are using the Silvair mobile app for iOS/iPadOS version 1.33.2 or later. If necessary, update to the newest version before troubleshooting any IV index issues.

Silvair mobile app versions earlier than 1.33.2 may not be able to connect to an island with a lower IV index than the highest one previously seen by the app for this network. This was fixed in version 1.33.2. Starting from this version, the Silvair mobile app will be able to connect to any device in the network, regardless of its IV index.

3.2 Resolving IV index issues

We recommend resolving IV index issues in the following sequence:

1. Connect all islands so they are part of the network.
2. Find the highest IV index in the network.
3. Unify the IV index of the remaining devices with the highest IV index value.

3.2.1 Connecting all islands

1. Use the 'mesh quality test' in the Silvair mobile app for iOS/iPadOS from different places in the building to find islands. These will be groups of devices that are consistently out of range. They will be displayed in red in the test.
2. To connect the island(s), install at least one device in a place where it can connect with both the network and the island and set it up as a relay. Use the mesh quality test to make sure that the island can now be seen. Repeat this step for each island.
3. If it is not possible to connect an island (for example because the islands are in different places, or the distance between them is too big), consider one of the following solutions:
    a. Set up each island as a separate project (recommended).
    b. Set up each island as a separate area. In this case, issues may arise when adding new devices/gateways or connecting to the island with the mobile app.

    Use the mesh quality test to make a note of which zones belong to which island.

3.2.2 Finding the highest IV index

To find the highest IV index in a network/area, use the Silvair mobile app for iOS/iPadOS to connect to a device in the island and read the IV index from the diagnostics panel (Diagnostic > Element 0 – Silvair Debug Server > IV Index).

1. Make a note of the value.
2. Repeat this step for each part of the network (including any islands).

Now, you will know all the IV indexes that appear in the network and the highest IV index in the network will later be recorded in the Silvair cloud.

3.2.3 Unifying the IV index

To unify the IV index of a network or area at the highest value, use one of these methods:

- Reprovisioning – unprovision all devices that do not already have the highest IV index and reprovision them (recommended). Make sure that no islands are created.
- Power cycling – leave only the zones with the highest IV index powered on and power cycle each of the remaining zones one by one until each device has the highest IV index (leave the power off for 1 minute each time). You may need to power cycle a zone multiple times.
- Using a battery-powered device – add a battery-powered device to each zone with a lower IV index using the mobile app for iOS/iPadOS. On provisioning, the device will receive from the cloud the highest IV index seen in the network. Power cycle the zone as many times as is required for each device to have the highest IV index (use the Silvair mobile app for iOS/iPadOS to check) and leave the power off for 1 minute each time. Repeat this step for each zone with a lower IV index.

3.3 Common IV index issues

The following are the most common IV index issues and the recommended steps to resolve them:

- **A new device added to a part of the network (for example an island) cannot be controlled (via switch or sensor) as it has a different IV index than the other devices already in that zone**
    1. Reprovision all other devices in the island or power cycle them (force the IV Index Recovery procedure) to have their IV index increased to the highest value.
    2. Use the mesh quality test and also the 'Test' tab in the Silvair mobile app for iOS/iPadOS. When all devices can be seen and controlled, then the IV index has been unified in this area.
- **The Silvair mobile app cannot connect to an island which has a lower IV index than the rest of the network**:
    1. Make sure that you are using the Silvair mobile app for iOS/iPadOS version 1.33.2.
    2. Make sure that you are standing as far away from other areas as possible.[3]
    3. Restart the app and try again.
    4. If there is still no connection, go back to the project list, go to the project and area again, and select the zone you want to connect to. You may need to repeat this a few times.
- **A gateway has been added to an area but it cannot connect to / collect data from some (or any) devices in the area**:
    1. Connect any islands in the area to the rest of the network.
    2. If you cannot connect the island, set up each island as a separate area.
    3. Check if there are any differences in the IV index between devices in the area.
    4. Use reprovisioning or power cycling (forcing the IV Index Recovery procedure) to unify the IV index in this area.
- **A gateway has been added to an area but it cannot connect to / collect data from devices in other areas**:
    1. Check if the IV index in the area that cannot be connected to is different from the IV index in the area(s) where the gateway is working correctly.
    2. Use reprovisioning or power cycling (forcing the IV Index Recovery procedure) to unify the IV index in the area(s) with a lower IV index with the highest IV index value in the project.

[3] This is to minimize the chances of connecting to a proxy device in another area that has a higher IV index.

4. Best practices

1. When adding devices to projects, continue as described in *SN-202 Optimizing mesh network performance* to make sure that all devices are in range. The result of the mesh quality test in each area must be 100%.
2. Use the Silvair mobile app for iOS/iPadOS version 1.33.2 or later. You may need to update the app via the App Store.
3. Use firmware version 2.30 or later. With this version, an improved IV Index Recovery mechanism has been introduced that prevents desync of the IV index in case of connection issues. See *SN-208 OTA Firmware update for provisioned devices* for how to update the firmware of your devices.

5. Document revisions

Revision	Date	Editor	Changes
1.2	11 January 2024	GM	Added best practice to use firmware version 2.30 or later. Updated the “IV Index Recovery procedure” section. Minor edits.
1.1	16 November 2023	GM	Clarified where the mobile app for iOS/iPadOS is required. Corrected a link to an external document. Minor edits.
1.0	20 July 2023	ES	Initial revision.

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