



# **SoftDevice Specification**

## **S132 SoftDevice v3.0**

2016-07-29

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# Chapter 1

## S132 SoftDevice

The S132 SoftDevice is a *Bluetooth*<sup>®</sup> low energy (BLE) Central and Peripheral protocol stack solution. It supports up to eight connections with an additional Observer and a Broadcaster role all running concurrently. The S132 SoftDevice integrates a BLE Controller and Host, and provides a full and flexible API for building *Bluetooth*<sup>®</sup> Smart nRF52 System on Chip (SoC) solutions.

Key features	Applications
<ul style="list-style-type: none"> <li>• <i>Bluetooth</i><sup>®</sup> 4.2 compliant low energy single-mode protocol stack suitable for <i>Bluetooth</i><sup>®</sup> Smart products               <ul style="list-style-type: none"> <li>• Concurrent Central, Observer, Peripheral, and Broadcaster roles with up to eight concurrent connections along with one observer and one broadcaster</li> <li>• Configurable number of connections and bandwidth per connection to optimize memory and performance</li> <li>• Configurable attribute table size</li> <li>• Custom UUID support</li> <li>• Link layer</li> <li>• LL Privacy</li> <li>• LE Data Packet Length Extension</li> <li>• L2CAP, ATT, and SM protocols</li> <li>• LE Secure Connections pairing model</li> <li>• GATT and GAP APIs</li> <li>• GATT Client and Server</li> <li>• Configurable ATT MTU</li> </ul> </li> <li>• Complementary nRF5 SDK including <i>Bluetooth</i><sup>®</sup> profiles and example applications</li> <li>• Master Boot Record for over-the-air device firmware update               <ul style="list-style-type: none"> <li>• SoftDevice, application, and bootloader can be updated separately</li> </ul> </li> <li>• Memory isolation between the application and the protocol stack for robustness and security</li> <li>• Thread-safe supervisor-call based API</li> <li>• Asynchronous, event-driven behavior</li> <li>• No RTOS dependency               <ul style="list-style-type: none"> <li>• Any RTOS can be used</li> </ul> </li> <li>• No link-time dependencies               <ul style="list-style-type: none"> <li>• Standard ARM<sup>®</sup> Cortex<sup>®</sup>-M4 project configuration for application development</li> </ul> </li> <li>• Support for concurrent and non-concurrent multiprotocol operation               <ul style="list-style-type: none"> <li>• Concurrent with the <i>Bluetooth</i><sup>®</sup> stack using Radio Timeslot API</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Sports and fitness devices               <ul style="list-style-type: none"> <li>• Sports watches</li> <li>• Bike computers</li> </ul> </li> <li>• Personal Area Networks               <ul style="list-style-type: none"> <li>• Health and fitness sensor and monitoring devices</li> <li>• Medical devices</li> <li>• Key fobs and wrist watches</li> </ul> </li> <li>• Home automation</li> <li>• AirFuel wireless charging</li> <li>• Remote control toys</li> <li>• Computer peripherals and I/O devices               <ul style="list-style-type: none"> <li>• Mice</li> <li>• Keyboards</li> <li>• Multi-touch trackpads</li> </ul> </li> <li>• Interactive entertainment devices               <ul style="list-style-type: none"> <li>• Remote controls</li> <li>• Gaming controllers</li> </ul> </li> </ul>

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Key features	Applications
<ul style="list-style-type: none"><li>• Alternate protocol stack in application space</li><li>• Support for control of external Power Amplifiers and Low Noise Amplifiers</li></ul>	

# Chapter 2

## Revision history

Date	Version	Description
August 2016	3.0	<p>Corresponding to SoftDevice S132 version 3.0.0.</p> <p>Updated:</p> <ul style="list-style-type: none"> <li>• List of key features in <a href="#">S132 SoftDevice</a> on page 5.</li> <li>• <a href="#">Bluetooth low energy protocol stack</a> on page 34, adding: <ul style="list-style-type: none"> <li>• MTU exchange procedure and Write long characteristic values in <a href="#">Table 18: GATT features in the BLE stack</a> on page 37.</li> <li>• Numeric comparison in <a href="#">Table 19: Security Manager (SM) features in the BLE stack</a> on page 38.</li> <li>• Configurable ATT_MTU size in <a href="#">Table 20: Attribute Protocol (ATT) features in the BLE stack</a> on page 38.</li> <li>• Data packet length extension, LE Ping, Privacy, and Extended scanner filter policies in <a href="#">Table 21: Controller, Link Layer (LL) features in the BLE stack</a> on page 38.</li> </ul> </li> <li>• <a href="#">Radio Notification Signals</a> on page 41 with an additional section on Radio Notification with Connection Event Length Extension.</li> <li>• <a href="#">SoftDevice information structure</a> on page 54.</li> <li>• <a href="#">SoftDevice memory usage</a> on page 55: updated SoftDevice flash memory and RAM requirements.</li> <li>• <a href="#">Scheduling</a> on page 59 with an additional section on connection timing with Connection Event Length Extension, <a href="#">Connection timing with Connection Event Length Extension</a> on page 67.</li> <li>• <a href="#">BLE data throughput</a> on page 81: <ul style="list-style-type: none"> <li>• Updated figures of SoftDevice data throughput for single link on <a href="#">Table 39: Maximum data throughput with a single peripheral or central connection and a connection interval of 7.5 ms</a> on page 81,</li> <li>• Added table for maximum achievable single-link throughput: <a href="#">Table 39: Maximum data throughput with a single peripheral or central connection and a connection interval of 7.5 ms</a> on page 81.</li> </ul> </li> </ul>
April 2016	2.0	<p>Corresponding to SoftDevice S132 version 2.0.0. The SDS revision 1.0 is intentionally skipped to align with the SoftDevice version and with the S130 SDS version.</p> <p>Updated:</p> <ul style="list-style-type: none"> <li>• <a href="#">SoftDevice Manager</a> on page 12. Added documentation on (previously in Appendix A): <ul style="list-style-type: none"> <li>• Clock source,</li> <li>• Power management,</li> </ul> </li> </ul>

Date	Version	Description
		<ul style="list-style-type: none"> <li>• Memory isolation and runtime protection</li> <li>• <a href="#">Hardware peripherals</a> on page 18.</li> <li>• <a href="#">Programmable peripheral interconnect (PPI)</a> on page 21. Documented PPI channel changes.</li> <li>• <a href="#">Flash memory API</a> on page 23. Documented changes and new numbers.</li> <li>• <a href="#">Profile and service support</a> on page 34. Updated the list of profiles and services currently adopted by the <i>Bluetooth</i><sup>®</sup> Special Interest Group.</li> <li>• <a href="#">Radio Notification</a> on page 41.</li> <li>• <a href="#">Master Boot Record</a> on page 51.</li> <li>• <a href="#">Scheduling</a> on page 59 (previously Chapter 14: Multilink scheduling).</li> <li>• <a href="#">Interrupt model and processor availability</a> on page 70. Updated section to align with the new SoftDevice priority level structure.</li> <li>• <a href="#">BLE data throughput</a> on page 81. Updated documentation with new numbers.</li> </ul> <p>Added:</p> <ul style="list-style-type: none"> <li>• <a href="#">Application Programming Interface (API)</a> on page 11 (previously in Appendix A). Now also including section <a href="#">Error handling</a> on page 11.</li> <li>• <a href="#">BLE role configuration</a> on page 40.</li> <li>• <a href="#">Power Amplifier and Low Noise Amplifier control configuration (PA/LNA)</a> on page 49.</li> <li>• <a href="#">SoftDevice memory usage</a> on page 55 (<a href="#">Memory resource map and usage</a> on page 55 and <a href="#">Attribute table size</a> on page 57 previously in Chapter 13: System on Chip resource requirements; Call Stack and Heap information previously in Appendix A can be found under <a href="#">Memory resource requirements</a> on page 56).</li> <li>• <a href="#">SoftDevice timing-activities and priorities</a> on page 59.</li> <li>• <a href="#">Timeslot API timing</a> on page 67.</li> </ul> <p>Several chapters have been restructured, relocated and revised. Appendix A is removed.</p>
June 2015	0.5	Preliminary release.



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# Chapter 3

## Documentation

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Additional recommended reading for developing applications using the SoftDevice on the nRF52 SoC includes the product specification, errata, compatibility matrix, and *Bluetooth*<sup>®</sup> core specification.

A list of the recommended documentation for the SoftDevice is given in [Table 1: S132 SoftDevice core documentation](#) on page 9.

**Table 1: S132 SoftDevice core documentation**

Documentation	Description
<a href="#">nRF52832 Product Specification</a>	Contains a description of the hardware, peripherals, and electrical specifications specific to the nRF52832 IC.
<a href="#">nRF52832 Errata</a>	Contains information on anomalies related to the nRF52832 IC.
<a href="#">nRF52 Series Compatibility Matrix</a>	Contains information on the compatibility between nRF52 Integrated Circuit (IC) revisions, SoftDevices and SoftDevice Specifications, SDKs, development kits, documentation, and Qualified Design Identifications (QDIDs).
<a href="#">Bluetooth Core Specification</a>	The <i>Bluetooth</i> <sup>®</sup> Core Specification version 4.2, Volumes 1, 3, 4, and 6, describes <i>Bluetooth</i> <sup>®</sup> terminology which is used throughout the SoftDevice Specification.

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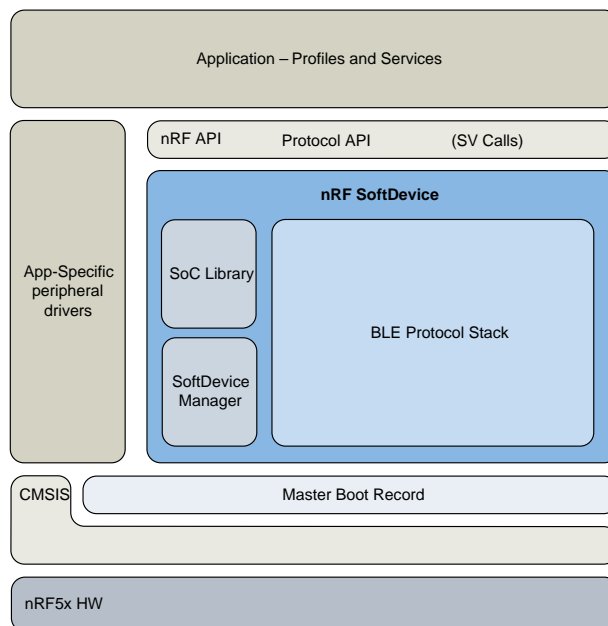
# Chapter 4

## Product overview

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The S132 SoftDevice is a precompiled and linked binary image implementing a *Bluetooth*<sup>®</sup> 4.2 low energy protocol stack for the nRF52 Series of SoCs.

See the [nRF52 Series Compatibility Matrix](#) for SoftDevice/IC compatibility information.



**Figure 1: System on Chip application with the SoftDevice**

Figure 1: System on Chip application with the SoftDevice on page 10 is a block diagram of the nRF52 series software architecture. It includes the standard ARM<sup>®</sup> CMSIS interface for nRF52 hardware, a master boot record, profile and application code, application specific peripheral drivers, and a firmware module identified as a SoftDevice.

A SoftDevice consists of three main components:

- SoC Library - Implementation and nRF API for shared hardware resource management (application coexistence).
- SoftDevice Manager - Implementation and nRF API for SoftDevice management (enabling/disabling the SoftDevice, etc.).
- *Bluetooth*<sup>®</sup> 4.2 low energy protocol stack - Implementation of protocol stack and API.

The Application Programming Interface (API) is a set of standard C language functions and data types, provided as a series of header files, that give the application complete compiler and linker independence from the SoftDevice implementation. See [Application Programming Interface \(API\)](#) on page 11 for more details.

The SoftDevice enables the application developer to develop their code as a standard ARM<sup>®</sup> Cortex<sup>®</sup> -M4 project without having the need to integrate with proprietary IC vendor software frameworks. This means that any ARM<sup>®</sup> Cortex<sup>®</sup> -M4-compatible toolchain can be used to develop *Bluetooth*<sup>®</sup> low energy applications with the SoftDevice.

The SoftDevice can be programmed onto compatible nRF52 Series ICs during both development and production.

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## Chapter 5

# Application Programming Interface (API)

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The SoftDevice Application Programming Interface (API) is available to applications as a C programming language interface based on SuperVIsor Calls (SVC) and defined in a set of header files.

In addition to a Protocol API enabling wireless applications, there is an nRF API that exposes the functionality of both the SoftDevice Manager and the SoC library.

**Important:** When the SoftDevice is disabled, only a subset of the SoftDevice APIs is available to the application (see [S132 SoftDevice API](#)). For more information about enabling and disabling the SoftDevice, see [SoftDevice enable and disable](#) on page 12.

SVCs are software triggered interrupts conforming to a procedure call standard for parameter passing and return values. Each SoftDevice API call triggers an SVC interrupt. The SoftDevice SVC interrupt handler locates the correct SoftDevice function, allowing applications to compile without any API function address information at compile time. This removes the necessity for the application to link the SoftDevice. The header files contain all information required for the application to invoke the API functions with standard programming language prototypes. This SVC interface makes SoftDevice API calls thread-safe; they can be invoked from the application's different priority levels without additional synchronization mechanisms.

**Important:** SoftDevice API functions can only be called from a lower interrupt priority level (higher numerical value for the priority level) than the SVC priority. For more information, see [Interrupt priority levels](#) on page 71.

## 5.1 Events - SoftDevice to application

Software triggered interrupts in a reserved IRQ are used to signal events from the SoftDevice to the application. The application is then responsible for handling the interrupt and for invoking the relevant SoftDevice functions to obtain the event data.

For details on how to implement the handling of these events, see the nRF5 Software Development Kit ([nRF5 SDK](#)) documentation.

## 5.2 Error handling

All SoftDevice API functions return a 32-bit error code. The application must check this error code to confirm whether a SoftDevice API function call was successful.

Unrecoverable failures (faults) detected by the SoftDevice will be reported to the application by a registered, fault handling callback function. A pointer to the fault handler must be provided by the application upon SoftDevice initialization. The fault handler is then used to notify of unrecoverable errors and the type of error is indicated as a parameter to the fault handler.

The following types of faults can be reported to the application through the fault handler:

- SoftDevice assertions.
- Attempts by the application to perform unallowed memory accesses, either against SoftDevice memory protection rules or to protected peripheral configuration registers at runtime.

The fault handler callback is invoked by the SoftDevice in HardFault context, with all interrupts disabled.

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# Chapter 6

## SoftDevice Manager

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The SoftDevice Manager (SDM) API allows the application to manage the SoftDevice on a top level. It controls the SoftDevice state and configures the behavior of certain SoftDevice core functionality.

When enabling the SoftDevice, the SDM configures the following:

- the low frequency clock (LFCLK) source, see [Clock source](#) on page 12.
- the interrupt management, see [SoftDevice enable and disable](#) on page 12.
- the embedded protocol stack.

In addition, it enables the SoftDevice RAM and peripheral protection. See [Memory isolation and runtime protection](#) on page 13.

Detailed documentation of the SDM API is made available with the Software Development Kits (SDK).

### 6.1 SoftDevice enable and disable

When the SoftDevice is not enabled, the Protocol API and parts of the SoC library API are not available to the application.

When the SoftDevice is not enabled, most of the SoC's resources are available to the application. However, the following restrictions apply:

- SVC numbers 0x10 to 0xFF are reserved.
- SoftDevice program (flash) memory is reserved.
- A few bytes of RAM are reserved. See [Memory resource map and usage](#) on page 55 for more details.

Once the SoftDevice has been enabled, more restrictions apply:

- Some RAM will be reserved. See [Memory isolation and runtime protection](#) on page 13 for more details.
- Some peripherals will be reserved. See [Hardware peripherals](#) on page 18 for more details.
- Some of the peripherals that are reserved will have a SoC library interface.
- Interrupts from the reserved SoftDevice peripherals will not be forwarded to the application. See [Interrupt forwarding to the application](#) on page 70 for more details.
- The reserved peripherals are reset upon SoftDevice disable.
- `nrf_nvic_` functions must be used instead of CMSIS `NVIC_` functions for safe use of the SoftDevice.
- SoftDevice activity in high priority levels may interrupt the application, increasing the maximum interrupt latency. For more information, see [Interrupt model and processor availability](#) on page 70

### 6.2 Clock source

The SoftDevice can use one of two available low frequency clock sources: the internal RC Oscillator, or external Crystal Oscillator.

The application must provide the selected clock source and some clock source characteristics, such as accuracy, when it enables the SoftDevice. The SoftDevice Manager is responsible for configuring the low frequency clock source and for keeping it calibrated, when the RC oscillator is the selected clock source.

If the SoftDevice is configured with the internal RC oscillator clock option, clock calibration is required periodically, and when a temperature change of more than 0.5 degrees has occurred to adjust the RC oscillator frequency. See the [nRF52832 Product Specification](#) for more information. The SoftDevice will perform this function automatically. The application may choose how often the SoftDevice will make a measurement to detect temperature change, depending on how frequently significant temperature changes are expected

to occur in the intended environment of the end product. It is recommended to use a temperature polling interval of 4 seconds, and to force clock calibration every second interval (.ctiv=32, .temp\_ctiv=2).

### 6.3 Power management

The SoftDevice implements a simple to use SoftDevice POWER API for optimized power management.

The application must use this API when the SoftDevice is enabled to ensure correct function. When the SoftDevice is disabled, the application must use the hardware abstraction (CMSIS) interfaces for power management directly.

When waiting for application events using the API, the CPU goes to an IDLE state whenever the SoftDevice is not using the CPU, and interrupts handled directly by the SoftDevice do not wake the application. Application interrupts will wake the application as expected. When going to system OFF, the API ensures the SoftDevice services are stopped before powering down.

### 6.4 Memory isolation and runtime protection

The SoftDevice data memory and peripherals can be sandboxed and runtime protected to prevent the application from interfering with the SoftDevice execution, ensuring robust and predictable performance.

Sandboxing<sup>1</sup> and runtime protection can allow memory access violations to be detected at development time. This ensures that developed applications will not inadvertently interfere with the correct functioning of the SoftDevice.

Sandboxing is enabled by default when the SoftDevice is enabled and disabled when the SoftDevice is disabled. When enabled, SoftDevice RAM and peripheral registers are protected against write access by the application. The application will have read access to SoftDevice RAM and peripheral registers.

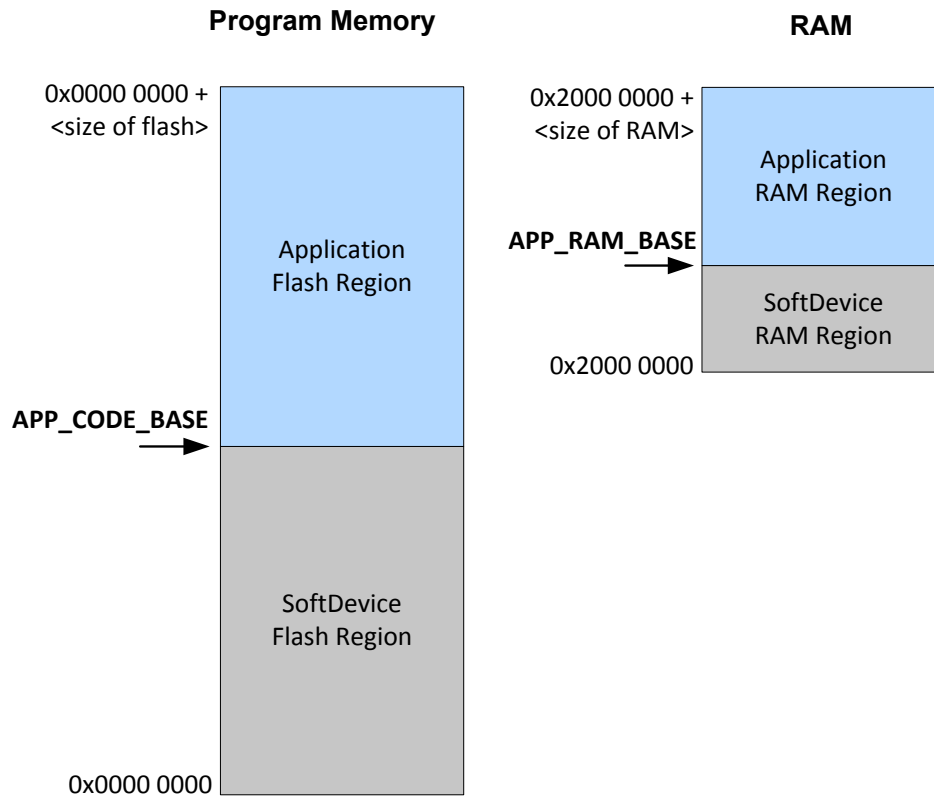
The program memory is divided into two regions at compile time. The SoftDevice Flash Region is located between addresses `0x00000000` and `APP_CODE_BASE - 1` and is occupied by the SoftDevice. The Application Flash Region is located between the addresses `APP_CODE_BASE` and the last valid address in the flash memory and is available to the application.

The RAM is split into two regions, which are defined at runtime, when the SoftDevice is enabled. The SoftDevice RAM Region is located between the addresses `0x20000000` and `APP_RAM_BASE - 1` and is used by the SoftDevice. The Application RAM Region is located between the addresses `APP_RAM_BASE` and the top of RAM and is available to the application.

[Figure 2: Memory region designation](#) on page 14 presents an overview of the regions.

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<sup>1</sup> A sandbox is a set of memory access restrictions imposed on the application.



**Figure 2: Memory region designation**

The SoftDevice uses a fixed amount of flash (program) memory. By contrast, the size of the SoftDevice RAM Region depends on whether the SoftDevice is enabled or not, and on the selected BLE protocol stack configuration. See [Role configuration](#) on page 57 for more details.

The amount of flash and RAM available to the application is determined by region size (kilobytes or bytes) and the `APP_CODE_BASE` and `APP_RAM_BASE` addresses which are the base addresses of the application code and RAM, respectively. The application code must be located between `APP_CODE_BASE` and `<size of flash>`. The application variables must be allocated in an area inside the Application RAM Region, located between `APP_RAM_BASE` and `<size of RAM>`. This area shall not overlap with the allocated RAM space for the call stack and heap, which is also located inside the Application RAM Region.

Example application program code address range:

`APP_CODE_BASE ≤ Program ≤ <size of flash>`

Example application RAM address range assuming call stack and heap location as shown in [Figure 24: Memory resource map](#) on page 55:

`APP_RAM_BASE ≤ RAM ≤ (0x2000 0000 + <size of RAM>) - (<Call Stack> + <Heap>)`

Sandboxing protects the SoftDevice RAM Region so that it cannot be written to by the application at runtime. Violation of sandboxing rules, for example an attempt to write to the protected SoftDevice memory, will result in the triggering of a fault (unrecoverable error handled by the application). See [Error handling](#) on page 11 for more information.

When the SoftDevice is disabled, all RAM, with the exception of a few bytes, is available to the application. See [Memory resource map and usage](#) on page 55 for more details. When the SoftDevice is enabled, RAM up to `APP_RAM_BASE` will be used by the SoftDevice and will be write protected.

The typical location of the call stack for an application using the SoftDevice is in the upper part of the Application RAM Region, so the application can place its variables from the end of the SoftDevice RAM Region (`APP_RAM_BASE`) to the beginning of the call stack space.

**Important:**

- The location of the call stack is communicated to the SoftDevice through the contents of the Main Stack Pointer (MSP) register.
- Do not change the value of MSP dynamically (i.e. never set the MSP register directly).
- The RAM located in the SoftDevice RAM Region will be overwritten once the SoftDevice is enabled.
- The SoftDevice RAM Region will not be cleared or restored to default values after disabling the SoftDevice, so the application must treat the contents of the region as uninitialized memory.

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## Chapter 7

# System on Chip (SoC) library

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The coexistence of Application and SoftDevice with safe sharing of common System on Chip (SoC) resources is ensured by the SoC library.

The features described in [Table 2: System on Chip features](#) on page 16 are implemented by the SoC library and can be used for accessing the shared hardware resources.

**Table 2: System on Chip features**

Feature	Description
Mutex	The SoftDevice implements atomic mutex acquire and release operations that are safe for the application to use. Use this mutex to avoid disabling global interrupts in the application, because disabling global interrupts will interfere with the SoftDevice and may lead to dropped packets or lost connections.
NVIC	Wrapper functions for the CMSIS NVIC functions provided by ARM®.  <b>Important:</b> To ensure reliable usage of the SoftDevice you must use the wrapper functions when the SoftDevice is enabled.
Rand	Provides random numbers from the hardware random number generator.
Power	Access to POWER block configuration while the SoftDevice is enabled: <ul style="list-style-type: none"><li>• Access to RESETREAS register</li><li>• Set power modes</li><li>• Configure power fail comparator</li><li>• Control RAM block power</li><li>• Use general purpose retention register</li><li>• Configure DC/DC converter state:<ul style="list-style-type: none"><li>• DISABLED</li><li>• ENABLED</li></ul></li></ul>
Clock	Access to CLOCK block configuration while the SoftDevice is enabled. Allows the HFCLK Crystal Oscillator source to be requested by the application.
Wait for event	Simple power management call for the application to use to enter a sleep or idle state and wait for an application event.
PPI	Configuration interface for PPI channels and groups reserved for an application.



Feature	Description
Radio Timeslot API	Schedule other radio protocol activity, or periods of radio inactivity. For more information, see <a href="#">Concurrent multiprotocol implementation using the Radio Timeslot API</a> on page 25.
Radio Notification	Configure Radio Notification signals on ACTIVE and/or nACTIVE. See <a href="#">Radio Notification Signals</a> on page 41.
Block Encrypt (ECB)	Safe use of 128-bit AES encrypt HW accelerator.
Event API	Fetch asynchronous events generated by the SoC library.
Flash memory API	Application access to flash write, erase, and protect. Can be safely used during all protocol stack states. See <a href="#">Flash memory API</a> on page 23.
Temperature	Application access to the temperature sensor.

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# Chapter 8

## System on Chip resource requirements

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This section describes how the SoftDevice, including the Master Boot Record (MBR), uses the System on Chip (SoC) resources. The SoftDevice requirements are shown for both when the SoftDevice is enabled and disabled.

The SoftDevice and MBR (see [Master Boot Record and bootloader](#) on page 51) are designed to be installed on the nRF SoC in the lower part of the code memory space. After a reset, the MBR will use some RAM to store state information. When the SoftDevice is enabled, it uses resources on the SoC including RAM and hardware peripherals like the radio. For the amount of RAM required by the SoftDevice see [SoftDevice memory usage](#) on page 55.

### 8.1 Hardware peripherals

SoftDevice access types are used to indicate the availability of hardware peripherals to the application. The availability varies per hardware peripheral and depends on whether the SoftDevice is enabled or disabled.

**Table 3: Hardware access type definitions**

Access type	Definition
Restricted	Used by the SoftDevice and outside the application sandbox. The application has limited access through the SoftDevice API.
Blocked	Used by the SoftDevice and outside the application sandbox. The application has no access.
Open	Not used by the SoftDevice. The application has full access.

**Table 4: Peripheral protection and usage by SoftDevice**

ID	Base address	Instance	Access SoftDevice enabled	Access SoftDevice disabled
0	0x40000000	CLOCK	Restricted	Open
0	0x40000000	POWER	Restricted	Open
0	0x40000000	BPROT	Restricted	Open
1	0x40001000	RADIO	Blocked <sup>5</sup>	Open
2	0x40002000	UART0 /UARTE0	Open	Open

ID	Base address	Instance	Access SoftDevice enabled	Access SoftDevice disabled
3	0x40003000	TWIM0 / TWIS0 / SPIM0 / SPIS0 / SPI0 / TWI0	Open	Open
4	0x40004000	SPI1 / TWIS1 / SPIM1 / TWI1 / TWIM1 / SPIS1	Open	Open
...				
6	0x40006000	GPIOE	Open	Open
7	0x40007000	SAADC	Open	Open
8	0x40008000	TIMER0	Blocked <sup>5</sup>	Open
9	0x40009000	TIMER1	Open	Open
10	0x4000A000	TIMER2	Open	Open
11	0x4000B000	RTC0	Blocked	Open
12	0x4000C000	TEMP	Restricted	Open
13	0x4000D000	RNG	Restricted	Open
14	0x4000E000	ECB	Restricted	Open
15	0x4000F000	CCM	Blocked <sup>5</sup>	Open
15	0x4000F000	AAR	Blocked <sup>5</sup>	Open
16	0x40010000	WDT	Open	Open
17	0x40011000	RTC1	Open	Open
18	0x40012000	QDEC	Open	Open
19	0x40013000	LPCOMP / COMP	Open	Open
20	0x40014000	EGU0 / SWI0	Open	Open
21	0x40015000	EGU1 / SWI1 / Radio Notification	Restricted <sup>6</sup>	Open
22	0x40016000	EGU2 / SWI2 / SoftDevice Event	Blocked	Open
23	0x40017000	EGU3 / SWI3	Open	Open
24	0x40018000	EGU4 / SWI4	Blocked	Open
25	0x40019000	EGU5 / SWI5	Blocked	Open
...				
30	0x4001E000	NVMC	Restricted	Open
31	0x4001F000	PPI	Open <sup>2</sup>	Open
32	0x40020000	MWU	Restricted <sup>3</sup>	Open

ID	Base address	Instance	Access SoftDevice enabled	Access SoftDevice disabled
33	0x40021000	PWM1	Open	Open
34	0x40022000	PWM2	Open	Open
35	0x40023000	SPI2 / SPIS2 / SPIM2	Open	Open
36	0x40024000	RTC2	Open	Open
37	0x40025000	I2S	Open	Open
38	0x40026000	FPU	Open	Open
NA	0x10000000	FICR	Blocked	Blocked
NA	0x10001000	UICR	Restricted	Open
NA	0x50000000	GPIO P0	Open	Open
NA	0xE000E100	NVIC	Restricted <sup>4</sup>	Open

## 8.2 Application signals – software interrupts (SWI)

Software interrupts are used by the SoftDevice to signal events to the application.

**Table 5: Allocation of software interrupt vectors to SoftDevice signals**

SWI	Peripheral ID	SoftDevice Signal
0	20	Unused by the SoftDevice and available to the application.
1	21	Radio Notification - optionally configured through API.
2	22	SoftDevice Event Notification.
3	23	Reserved.
4	24	SoftDevice processing - not user configurable.
5	25	SoftDevice processing - not user configurable.

<sup>2</sup> See section [Programmable peripheral interconnect \(PPI\)](#) on page 21 for limitations on the use of PPI when the SoftDevice is enabled.

<sup>3</sup> See section [Memory isolation and runtime protection](#) on page 13 and [Peripheral runtime protection](#) on page 22 for limitations on the use of MWU when the SoftDevice is enabled.

<sup>4</sup> Not protected. For robust system function, the application program must comply with the restriction and use the NVIC API for configuration when the SoftDevice is enabled.

<sup>5</sup> Available to the application through the Radio Timeslot API, see [Concurrent multiprotocol implementation using the Radio Timeslot API](#) on page 25.

<sup>6</sup> Blocked only when Radio Notification signal is enabled. See [Application signals – software interrupts \(SWI\)](#) on page 20 for software interrupt allocation.

### 8.3 Programmable peripheral interconnect (PPI)

PPI may be configured using the PPI API in the SoC library.

This API is available both when the SoftDevice is disabled and when it is enabled. It is also possible to configure the PPI using the Cortex Microcontroller Software Interface Standard (CMSIS) directly when the SoftDevice is disabled.

When the SoftDevice is disabled, all PPI channels and groups are available to the application. When the SoftDevice is enabled, some PPI channels and groups, as described in the table below, are in use by the SoftDevice.

When the SoftDevice is enabled, the application program must not change the configuration of PPI channels or groups used by the SoftDevice. Failing to comply with this will cause the SoftDevice to not operate properly.

**Table 6: Assigning PPI channels between the application and SoftDevice**

PPI channel allocation	SoftDevice enabled	SoftDevice disabled
Application	Channels 0 - 16	Channels 0 - 19
SoftDevice	Channels 17 - 19 <sup>7</sup>	-

**Table 7: Assigning preprogrammed channels between the application and SoftDevice**

PPI channel allocation	SoftDevice enabled	SoftDevice disabled
Application	-	Channels 20 - 31
SoftDevice	Channels 20 - 31	-

**Table 8: Assigning PPI groups between the application and SoftDevice**

PPI channel allocation	SoftDevice enabled	SoftDevice disabled
Application	Groups 0 - 3	Groups 0 - 5
SoftDevice	Groups 4 - 5	-

### 8.4 SVC number ranges

Application programs and SoftDevices use certain SVC numbers.

The table below shows which SVC numbers an application program can use and which numbers are used by the SoftDevice.

**Important:** The SVC number allocation does not change with the state of the SoftDevice (enabled or disabled).

**Table 9: SVC number allocation**

SVC number allocation	SoftDevice enabled	SoftDevice disabled
Application	0x00-0x0F	0x00-0x0F

<sup>7</sup> Available to the application in Radio Timeslot API timeslots, see [Concurrent multiprotocol implementation using the Radio Timeslot API](#) on page 25.

SVC number allocation	SoftDevice enabled	SoftDevice disabled
SoftDevice	0x10-0xFF	0x10-0xFF

## 8.5 Peripheral runtime protection

To prevent the application from accidentally disrupting the protocol stack in any way, the application sandbox also protects the peripherals used by the SoftDevice.

Protected peripheral registers are readable by the application. An attempt to perform a write to a protected peripheral register will result in a Hard Fault. See [Error handling](#) on page 11 for more details on faults due to unallowed memory access. Note that the peripherals are only protected when the SoftDevice is enabled, otherwise they are available to the application. See [Table 4: Peripheral protection and usage by SoftDevice](#) on page 18 for an overview of the peripherals with access restrictions due to the SoftDevice.

## 8.6 External and miscellaneous requirements

For correct operation of the SoftDevice, it is a requirement that the crystal oscillator (HFXO) startup time is less than 1.5 ms.

The external clock crystal and other related components must be chosen accordingly. Data for the crystal oscillator input can be found in the product specification ([nRF52832 Product Specification](#)) for the SoC.

When the SoftDevice is enabled the SEVONPEND flag in the SCR register of the CPU shall only be changed from main or low interrupt level (priority not higher than 4), otherwise the behavior of the SoftDevice is undefined and the SoftDevice might malfunction.

# Chapter 9

## Flash memory API

The System on Chip (SoC) flash memory API provides the application with flash write, flash erase, and flash protect support through the SoftDevice. Asynchronous flash memory operations can be safely performed during active BLE connections using the Flash memory API of the SoC library.

The flash memory accesses are scheduled to not disturb radio events. See [Flash API timing](#) on page 67 for details. If the protocol radio events are in a critical state, flash memory accesses may be delayed for a long period resulting in a time-out event. In this case, `NRF_EVT_FLASH_OPERATION_ERROR` will be returned in the application event handler. If this happens, retry the flash memory operation. Examples of typical critical phases of radio events include: connection setup, connection update, disconnection, and impending supervision time-out.

The probability of successfully accessing the flash memory decreases with increasing scheduler activity (i.e. radio activity and timeslot activity). With long connection intervals there will be a higher probability of accessing flash memory successfully. Use the guidelines in [Table 10: Behavior with BLE traffic and concurrent flash write/erase](#) on page 23 to improve the probability of flash operation success.

**Important:** Flash page (4096 bytes) erase can take up to 90 ms and a 4 byte flash write can take up to 338  $\mu$ s. A flash write must be made in chunks smaller or equal to the flash page size. Make flash writes in as small chunks as possible to increase probability of success, and reduce chances of affecting BLE performance.

**Table 10: Behavior with BLE traffic and concurrent flash write/erase**

BLE activity	Flash write/erase (flash write size is assumed to be four bytes)
High Duty cycle directed advertising	Does not allow flash operation while advertising is active (maximum 1.28 seconds). In this case, retrying flash operation will only succeed after the advertising activity has finished.
All possible BLE roles running concurrently (connections as a central, peripheral, advertiser, and scanner).	Low to medium probability of flash operation success Probability of success increases with: <ul style="list-style-type: none"> <li>• Lower bandwidth configurations.</li> <li>• Increase in connection interval and advertiser interval.</li> <li>• Decrease in scan window.</li> <li>• Increase in scan interval.</li> </ul>
8 high bandwidth connections as a central 1 high bandwidth connection as a peripheral All active connections fulfill the following criteria: <ul style="list-style-type: none"> <li>• Supervision time-out &gt; 6 x connection interval</li> <li>• Connection interval <math>\geq</math> 150 ms</li> <li>• All central connections have the same connection interval</li> </ul>	High probability of flash write success. Medium probability of flash erase success. (High probability if the connection interval is > 240 ms)
8 high bandwidth connections as a central	High probability of flash operation success.

BLE activity	Flash write/erase (flash write size is assumed to be four bytes)
<p>All active connections fulfill the following criteria:</p> <ul style="list-style-type: none"> <li>Supervision time-out &gt; 6 x connection interval</li> <li>Connection interval ≥ 150 ms</li> <li>All connections have the same connection interval</li> </ul>	
<p>8 low bandwidth connections as a central</p> <p>All active connections fulfill the following criteria:</p> <ul style="list-style-type: none"> <li>Supervision time-out &gt; 6 x connection interval</li> <li>Connection interval ≥ 110 ms</li> <li>All connections have the same connection interval</li> </ul>	<p>High probability of flash operation success.</p>
<p>1 connection as a peripheral</p> <p>All active connections fulfill the following criteria:</p> <ul style="list-style-type: none"> <li>Supervision time-out &gt; 6 x connection interval</li> <li>Connection interval ≥ 25 ms</li> </ul>	<p>High probability of flash operation success.</p>
<p>Connectable Undirected Advertising</p> <p>Nonconnectable Advertising</p> <p>Scannable Advertising</p> <p>Connectable Low Duty Cycle Directed Advertising</p>	<p>High probability of flash operation success.</p>
<p>No BLE activity</p>	<p>Flash operation will always succeed.</p>



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# Chapter 10

## Multiprotocol support

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Multiprotocol support allows a developer to implement their own 2.4 GHz proprietary protocol in the application; both when the SoftDevice is not in use (non-concurrent), or while the SoftDevice protocol stack is in use (concurrent). For concurrent multiprotocol implementations, the Radio Timeslot API allows the application protocol to safely schedule radio usage between BLE events.

### 10.1 Non-concurrent multiprotocol implementation

For non-concurrent operation a proprietary 2.4 GHz protocol can be implemented in the application program area and can access all hardware resources when the SoftDevice is disabled. The SoftDevice may be disabled and enabled without resetting the application in order to switch between a proprietary protocol stack and *Bluetooth*<sup>®</sup> communication.

### 10.2 Concurrent multiprotocol implementation using the Radio Timeslot API

The Radio Timeslot API allows the nRF52 device to be part of a network using the SoftDevice protocol stack and an alternative network of wireless devices at the same time.

The Radio Timeslot (or, simply, Timeslot) feature gives the application access to the radio and other restricted peripherals during defined time intervals, denoted as timeslots. The Timeslot feature achieves this by cooperatively scheduling the application's use of these peripherals with those of the SoftDevice. Using this feature, the application can run other radio protocols (third party custom or proprietary protocols running from application space) concurrently with the internal protocol stack(s) of the SoftDevice. It can also be used to suppress SoftDevice radio activity and to reserve guaranteed time for application activities with hard timing requirements, which cannot be met by using the SoC Radio Notifications.

The Timeslot feature is part of the SoC library. The feature works by having the SoftDevice time-multiplex access to peripherals between the application and itself. Through the SoC API, the application can open a Timeslot session and request timeslots. When a Timeslot request is granted, the application has exclusive and real-time access to the normally blocked RADIO, TIMER0, CCM, and AAR peripherals and can use these freely for the duration (length) of the timeslot, see [Table 3: Hardware access type definitions](#) on page 18 and [Table 4: Peripheral protection and usage by SoftDevice](#) on page 18.

#### 10.2.1 Request types

There are two types of Radio Timeslot requests, *earliest possible* Timeslot requests and *normal* Timeslot requests.

Timeslots may be requested as *earliest possible*, in which case the timeslot occurs at the first available opportunity. In the request, the application can limit how far into the future the timeslot may be placed.

**Important:** The first request in a session must always be *earliest possible* to create the timing reference point for later timeslots.

Timeslots may also be requested at a given time (*normal*). In this case, the application specifies in the request when the timeslot should start and the time is measured from the start of the previous timeslot.

The application may also request to extend an ongoing timeslot. Extension requests may be repeated, prolonging the timeslot even further.

Timeslots requested as *earliest possible* are useful for single timeslots and for non-periodic or non-timed activity. Timeslots requested at a given time relative to the previous timeslot are useful for periodic and timed

activities; for example, a periodic proprietary radio protocol. Timeslot extension may be used to secure as much continuous radio time as possible for the application; for example, running an “always on” radio listener.

### 10.2.2 Request priorities

Radio Timeslots can be requested at either high or normal priority, indicating how important it is for the application to access the specified peripherals. A Timeslot request can only be blocked or cancelled due to an overlapping SoftDevice activity that has a higher scheduling priority.

### 10.2.3 Timeslot length

A Radio Timeslot is requested for a given length. Ongoing timeslots have the possibility to be extended.

The length of the timeslot is specified by the application in the Timeslot request and ranges from 100  $\mu$ s to 100 ms. Longer continuous timeslots can be achieved by requesting to extend the current timeslot. A timeslot may be extended multiple times, as long as its duration does not extend beyond the time limits set by other SoftDevice activities, and up to a maximum length of 128 seconds.

### 10.2.4 Scheduling

The SoftDevice includes a scheduler which manages radio timeslots, priorities and sets up timers to grant timeslots.

Whether a Timeslot request is granted and access to the peripherals is given is determined by the following factors:

- The time the request is made,
- The exact time in the future the timeslot is requested for,
- The desired priority level of the request,
- The length of the requested timeslot.

[Timeslot API timing](#) on page 67 explains how timeslots are scheduled. Timeslots requested at high priority will cancel other activities scheduled at lower priorities in case of a collision. Requests for short timeslots have a higher probability of succeeding than requests for longer timeslots because shorter timeslots are easier to fit into the schedule.

**Important:** Radio Notification signals behave the same way for timeslots requested through the Radio Timeslot interface as for SoftDevice internal activities. See section [Radio Notification Signals](#) on page 41 for more information. If Radio Notifications are enabled, Radio Timeslots will be notified.

### 10.2.5 Performance considerations

The Radio Timeslot API shares core peripherals with the SoftDevice, and application-requested timeslots are scheduled along with other SoftDevice activities. Therefore, the use of the Timeslot feature may influence the performance of the SoftDevice.

The configuration of the SoftDevice should be considered when using the Radio Timeslot API. A configuration which uses more radio time for native protocol operation will reduce the available time for serving timeslots and result in a higher risk of scheduling conflicts.

All Timeslot requests should use the lowest priority to minimize disturbances to other activities. At this priority level only flash writes might be affected. The high priority should only be used when required, such as for running a radio protocol with certain timing requirements that are not met by using normal priority. By using the highest priority available to the Timeslot API, non-critical SoftDevice radio protocol traffic may be affected. The SoftDevice radio protocol has access to higher priority levels than the application. These levels will be used for important radio activity, for instance when the device is about to lose a connection.

See [Scheduling](#) on page 59 for more information on how priorities work together with other modules like the BLE protocol stack, the Flash API etc.

Timeslots should be kept as short as possible in order to minimize the impact on the overall performance of the device. Requesting a short timeslot will make it easier for the scheduler to fit in between other scheduled

activities. The timeslot may later be extended. This will not affect other sessions as it is only possible to extend a timeslot if the extended time is unreserved.

It is important to ensure that a timeslot has completed its outstanding operations before the time it is scheduled to end (based on its starting time and requested length), otherwise the SoftDevice behavior is undefined and may result in an unrecoverable fault.

## 10.2.6 Radio Timeslot API

This section describes the calls, events, signals, and return actions of the Radio Timeslot API.

A Timeslot session is opened and closed using API calls. Within a session, there is an API call to request timeslots. For communication back to the application the feature will generate events, which are handled by the normal application event handler, and signals, which must be handled by a callback function (the signal handler) provided by the application. The signal handler can also return actions to the SoftDevice. Within a timeslot, only the signal handler is used.

**Important:** The API calls, events, and signals are only given by their full names in the tables where they are listed the first time. Elsewhere, only the last part of the name is used.

### 10.2.6.1 API calls

These are the API calls defined for the S132 SoftDevice:

**Table 11: API calls**

API call	Description
sd_radio_session_open()	Open a radio timeslot session.
sd_radio_session_close()	Close a radio timeslot session.
sd_radio_request()	Request a radio timeslot.

### 10.2.6.2 Radio Timeslot events

Events come from the SoftDevice scheduler and are used for Radio Timeslot session management.

Events are received in the application event handler callback function, which will typically be run in an application interrupt, see [Events - SoftDevice to application](#) on page 11. The following events are defined:

**Table 12: Radio Timeslot events**

Event	Description
NRF_EVT_RADIO_SESSION_IDLE	Session status: The current timeslot session has no remaining scheduled timeslots.
NRF_EVT_RADIO_SESSION_CLOSED	Session status: The timeslot session is closed and all acquired resources are released.
NRF_EVT_RADIO_BLOCKED	Timeslot status: The last requested timeslot could not be scheduled, due to a collision with already scheduled activity or for other reasons.
NRF_EVT_RADIO_CANCELED	Timeslot status: The scheduled timeslot was canceled due to overlapping activity of higher priority.
NRF_EVT_RADIO_SIGNAL_CALLBACK_INVALID_RETURN	Signal handler: The last signal handler return value contained invalid parameters and the timeslot was ended.

### 10.2.6.3 Radio Timeslot signals

Signals come from the peripherals and arrive within a Radio Timeslot.

Signals are received in a signal handler callback function that the application must provide. The signal handler runs in interrupt priority level 0, which is the highest priority in the system, see section [Interrupt priority levels](#) on page 71.

**Table 13: Radio Timeslot signals**

Signal	Description
NRF_RADIO_CALLBACK_SIGNAL_TYPE_START	Start of the timeslot. The application now has exclusive access to the peripherals for the full length of the timeslot.
NRF_RADIO_CALLBACK_SIGNAL_TYPE_RADIO	Radio interrupt, for more information, see chapter 2.4 GHz radio (RADIO) in the nRF52 Reference Manual.
NRF_RADIO_CALLBACK_SIGNAL_TYPE_TIMER0	Timer interrupt, for more information, see chapter Timer/counter (TIMER) in the nRF52 Reference Manual.
NRF_RADIO_CALLBACK_SIGNAL_TYPE_EXTEND_SUCCEEDED	The latest extend action succeeded.
NRF_RADIO_CALLBACK_SIGNAL_TYPE_EXTEND_FAILED	The latest extend action failed.

#### 10.2.6.4 Signal handler return actions

The return value from the application signal handler to the SoftDevice contains an action.

**Table 14: Signal handler action return values**

Signal	Description
NRF_RADIO_SIGNAL_CALLBACK_ACTION_NONE	The timeslot processing is not complete. The SoftDevice will take no action.
NRF_RADIO_SIGNAL_CALLBACK_ACTION_END	The current timeslot has ended. The SoftDevice can now resume other activities.
NRF_RADIO_SIGNAL_CALLBACK_ACTION_REQUEST_AND_END	The current timeslot has ended. The SoftDevice is requested to schedule a new timeslot, after which it can resume other activities.
NRF_RADIO_SIGNAL_CALLBACK_ACTION_EXTEND	The SoftDevice is requested to extend the ongoing timeslot.

#### 10.2.6.5 Ending a timeslot in time

The application is responsible for keeping track of timing within the Radio Timeslot and for ensuring that the application's use of the peripherals does not last for longer than the granted timeslot length.

For these purposes, the application is granted access to the TIMER0 peripheral for the length of the timeslot. This timer is started from zero by the SoftDevice at the start of the timeslot, and is configured to run at 1 MHz. The recommended practice is to set up a timer interrupt that expires before the timeslot expires, with enough time left of the timeslot to do any clean-up actions before the timeslot ends. Such a timer interrupt can also be used to request an extension of the timeslot, but there must still be enough time to clean up if the extension is not granted.

**Important:** The scheduler uses the low frequency clock source for time calculations when scheduling events. If the application uses a TIMER (sourced from the current high frequency clock source) to calculate and signal the end of a timeslot, it must account for the possible clock drift between the high frequency clock source and the low frequency clock source.

### 10.2.6.6 The signal handler runs at interrupt priority level 0

The signal handler runs at interrupt priority level 0, which is the highest priority. Therefore, it cannot be interrupted by any other activity.

Since the signal handler runs at a higher interrupt priority (lower numerical value for the priority level) than the SVC calls (see [Interrupt priority levels](#) on page 71), SVC calls are not available in the signal handler.

**Important:** It is a requirement that processing in the signal handler does not exceed the granted time of the timeslot. If it does, the behavior of the SoftDevice is undefined and the SoftDevice may malfunction.

The signal handler may be called several times during a timeslot. It is recommended to use the signal handler only for real time signal handling. When the application has handled the signal, it can exit the signal handler and wait for the next signal, if it wants to do other (less time critical) processing at lower interrupt priority (higher numerical value for the priority level) while waiting.

## 10.3 Radio Timeslot API usage scenarios

In this section several Radio Timeslot API usage scenarios are provided with descriptions of the sequence of events within them.

### 10.3.1 Complete session example

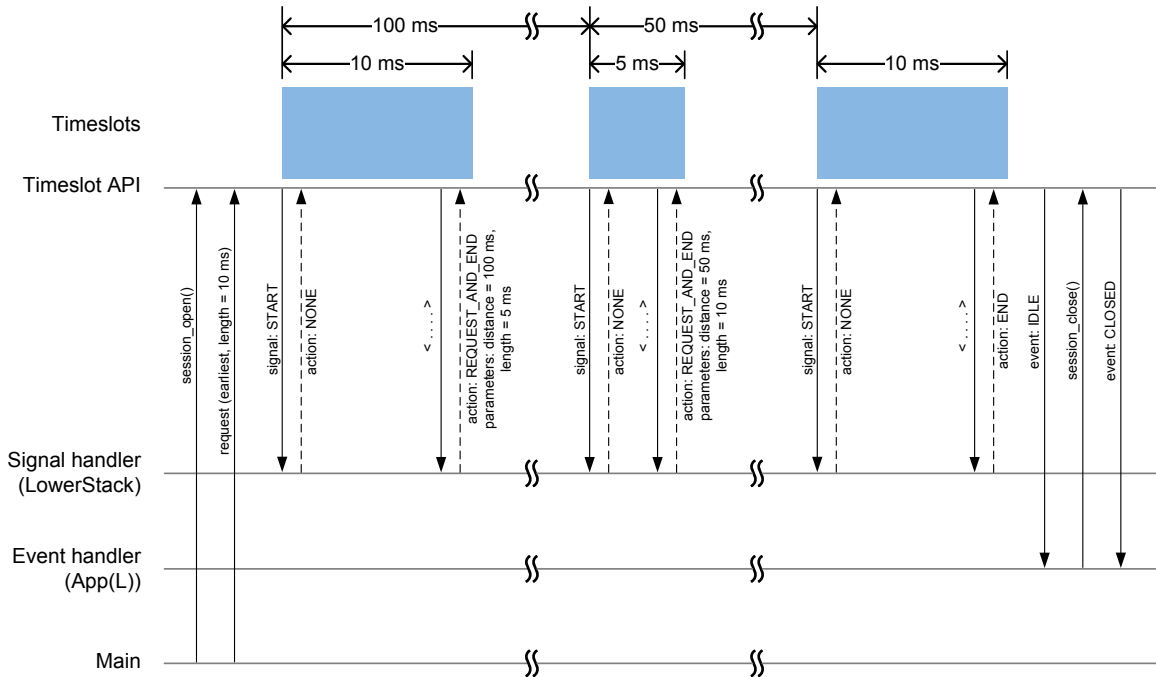
This section describes a complete Radio Timeslot session.

[Figure 3: Complete Radio Timeslot session example](#) on page 30 shows a complete Timeslot session. In this case, only timeslot requests from the application are being scheduled, there is no SoftDevice activity.

At start, the application calls the API to open a session and to request a first timeslot (which must be of type *earliest possible*). The SoftDevice schedules the timeslot. At the start of the timeslot, the SoftDevice calls the application signal handler with the START signal. After this, the application is in control and has access to the peripherals. The application will then typically set up TIMER0 to expire before the end of the timeslot, to get a signal indicating that the timeslot is about to end. In the last signal in the timeslot, the application uses the signal handler return action to request a new timeslot 100 ms after the first.

All subsequent timeslots are similar (see the middle timeslot in [Figure 3: Complete Radio Timeslot session example](#) on page 30). The signal handler is called with the START signal at the start of the timeslot. The application then has control, but must arrange for a signal to come towards the end of the timeslot. As the return value for the last signal in the timeslot, the signal handler requests a new timeslot using the REQUEST\_AND\_END action.

Eventually, the application does not require the radio any more. So, at the last signal in the last timeslot ([Figure 3: Complete Radio Timeslot session example](#) on page 30), the application returns END from the signal handler. The SoftDevice then sends an IDLE event to the application event handler. The application calls session\_close, and the SoftDevice sends the CLOSED event. The session has now ended.

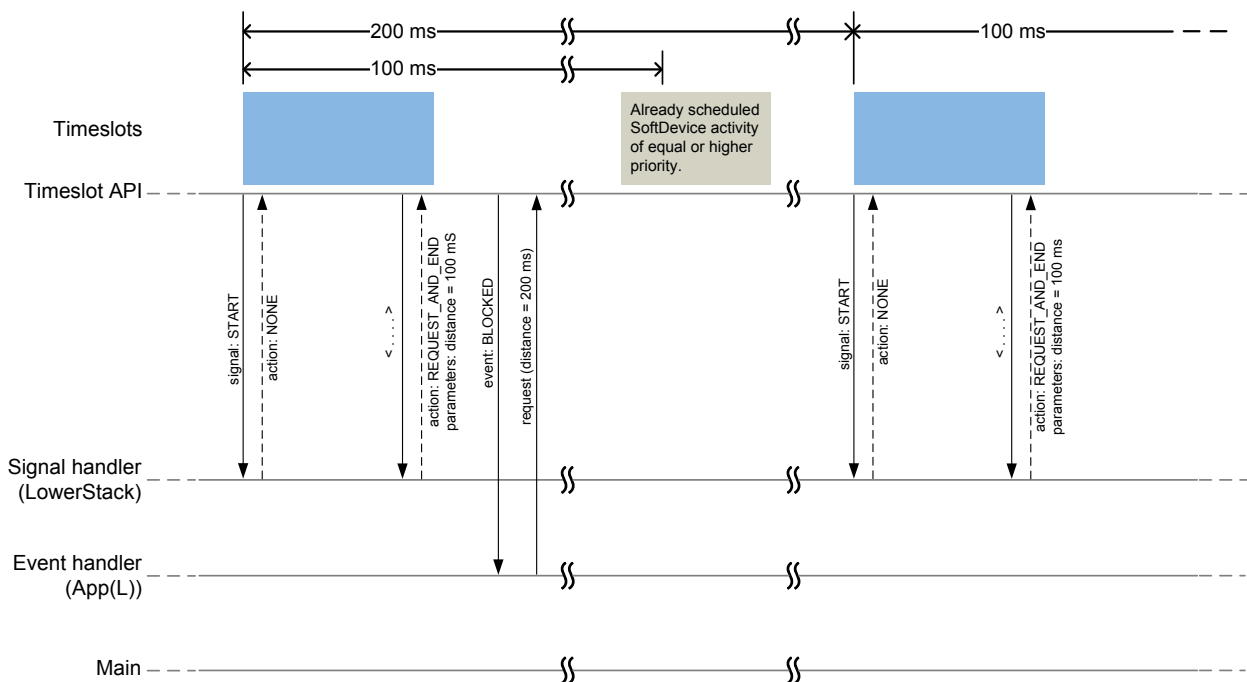


**Figure 3: Complete Radio Timeslot session example**

### 10.3.2 Blocked timeslot scenario

Radio Timeslot requests may be blocked due to an overlap with activities already scheduled by the SoftDevice.

Figure 4: Blocked timeslot scenario on page 30 shows a situation in the middle of a session where a requested timeslot cannot be scheduled. At the end of the first timeslot illustrated here, the application signal handler returns a REQUEST\_AND\_END action to request a new timeslot. The new timeslot cannot be scheduled as requested, because of a collision with an already scheduled SoftDevice activity. The application is notified about this by a BLOCKED event to the application event handler. The application then makes a new request for a later point in time. This request succeeds (it does not collide with anything), and a new timeslot is eventually scheduled.



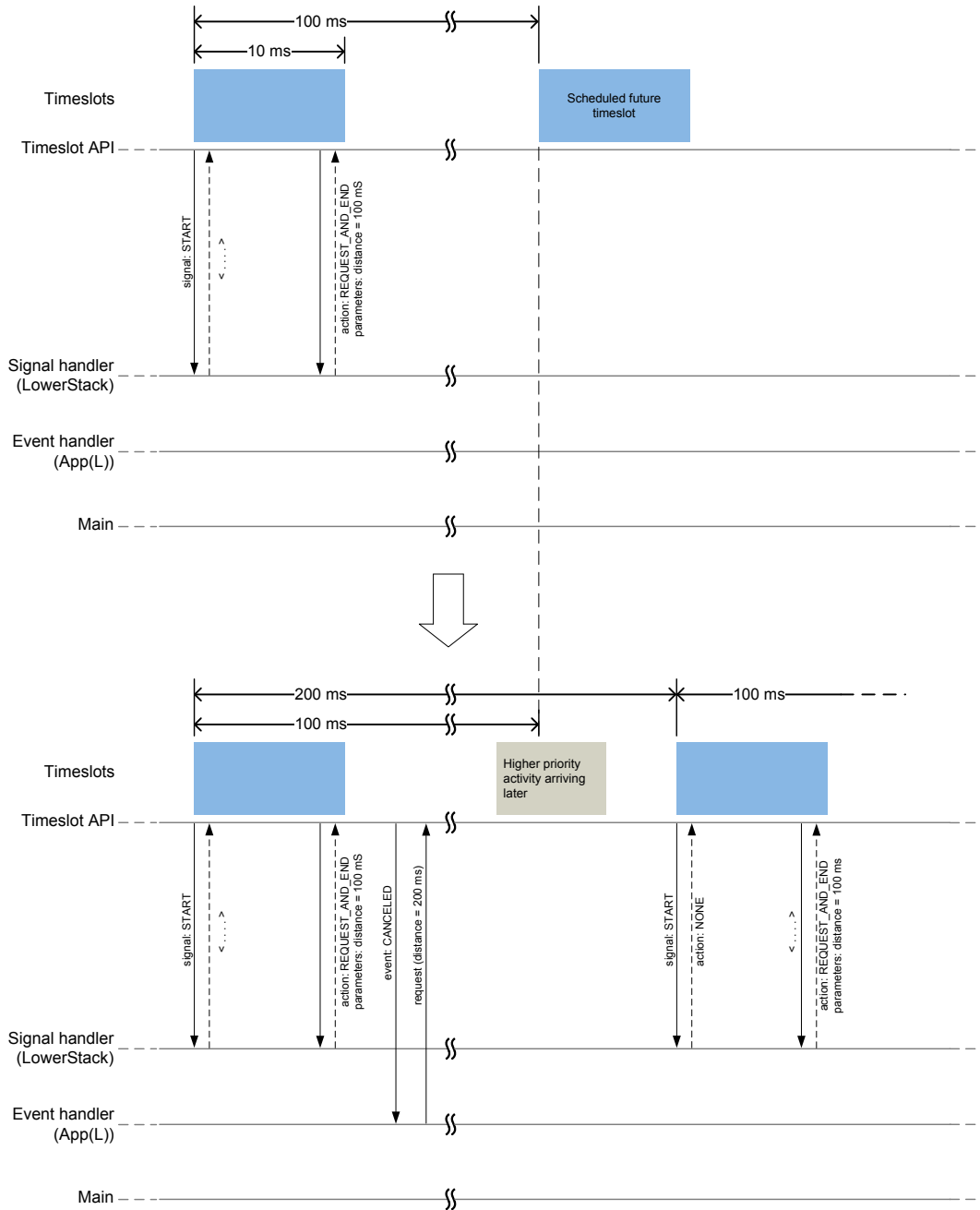
**Figure 4: Blocked timeslot scenario**

### 10.3.3 Canceled timeslot scenario

Situations may occur in the middle of a session where a requested and scheduled application radio timeslot is being revoked.

Figure 5: [Canceled timeslot scenario](#) on page 32 shows a situation in the middle of a session where a requested and scheduled application timeslot is being revoked. The upper part of the figure shows that the application has ended a timeslot by returning the REQUEST\_AND\_END action, and the new timeslot has been scheduled. The new scheduled timeslot has not started yet, as its starting time is in the future. The lower part of the figure shows the situation some time later.

In the meantime, the SoftDevice has requested some reserved time for a higher priority activity that overlaps with the scheduled application timeslot. To accommodate the higher priority request the application timeslot is removed from the schedule and, instead, the higher priority SoftDevice activity is scheduled. The application is notified about this by a CANCELED event to the application event handler. The application then makes a new request at a later point in time. That request succeeds (it does not collide with anything), and a new timeslot is eventually scheduled.



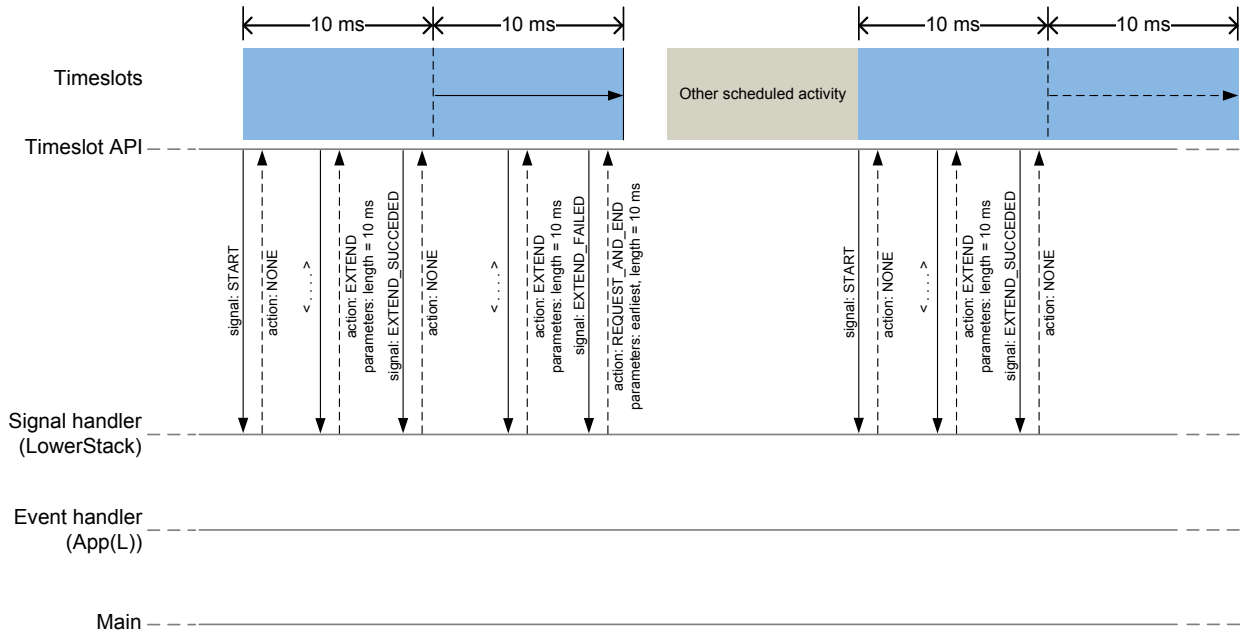
**Figure 5: Canceled timeslot scenario**

### 10.3.4 Radio Timeslot extension example

An application can use Radio Timeslot extension to create long continuous timeslots that will give the application as much radio time as possible while disturbing the SoftDevice activities as little as possible.

In the first timeslot in [Figure 6: Radio Timeslot extension example](#) on page 33 the application uses the signal handler return action to request an extension of the timeslot. The extension is granted, and the timeslot is seamlessly prolonged. The second attempt to extend the timeslot fails, as a further extension would cause a collision with a SoftDevice activity that has been scheduled. Therefore, the application makes a new request, of type earliest. This results in a new Radio Timeslot being scheduled immediately after the SoftDevice activity. This new timeslot can be extended a number of times.





**Figure 6: Radio Timeslot extension example**

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## Chapter 11

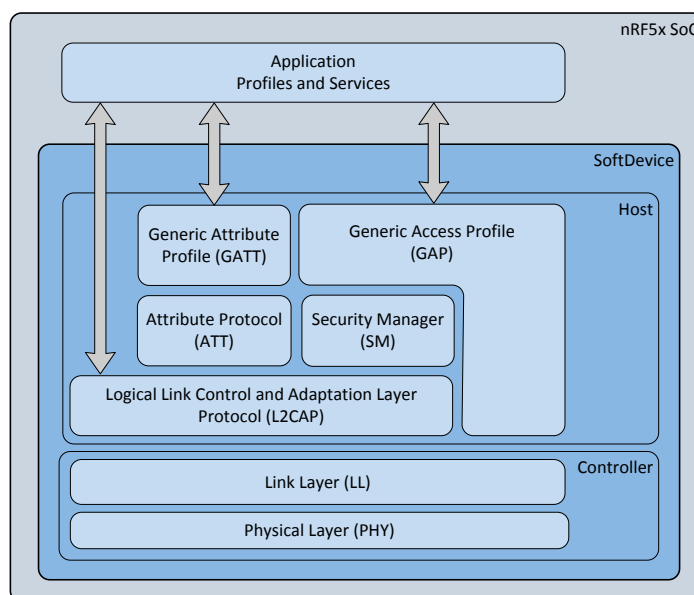
# Bluetooth<sup>®</sup> low energy protocol stack

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The Bluetooth<sup>®</sup> 4.2 compliant low energy Host and Controller implemented by the SoftDevice are fully qualified with multi-role support (Central, Observer, Peripheral, and Broadcaster).

The SoftDevice allows applications to implement standard Bluetooth<sup>®</sup> low energy profiles as well as proprietary use case implementations. The API is defined above the Generic Attribute Protocol (GATT), Generic Access Profile (GAP), and Logical Link Control and Adaptation Protocol (L2CAP).

The nRF5 Software Development Kit (nRF5 SDK) complements the SoftDevice with Service and Profile implementations. Single-mode System on Chip (SoC) applications are enabled by the full BLE protocol stack and nRF52 Series SoC.



**Figure 7: SoftDevice stack architecture**

### 11.1 Profile and service support

This section lists the profiles and services adopted by the Bluetooth Special Interest Group at the time of publication of this document.

The SoftDevice supports all profiles and services (with exceptions as noted in [Table 15: Supported profiles and services](#) on page 34) as well as additional proprietary profiles.

**Table 15: Supported profiles and services**

Adopted profile	Adopted services
HID over GATT	HID Battery Device Information

Adopted profile	Adopted services
Heart Rate	Heart Rate Device Information
Proximity	Link Loss Immediate Alert Tx Power
Blood Pressure	Blood Pressure Device Information
Health Thermometer	Health Thermometer Device Information
Glucose	Glucose Device Information
Phone Alert Status	Phone Alert Status
Alert Notification	Alert Notification
Time	Current Time Next DST Change Reference Time Update
Find Me	Immediate Alert
Cycling Speed and Cadence	Cycling Speed and Cadence Device Information
Running Speed and Cadence	Running Speed and Cadence Device Information
Location and Navigation	Location and Navigation
Cycling Power	Cycling Power
Scan Parameters	Scan Parameters
Weight Scale	Weight Scale Body Composition User Data Device Information
Continuous Glucose Monitoring	Continuous Glucose Monitoring Bond Management Device Information
Environmental Sensing	Environmental Sensing

Adopted profile	Adopted services
Pulse Oximeter	Pulse Oximeter Device Information Bond Management Battery Current Time
Object Transfer (Currently not supported by the SoftDevice)	Object Transfer
Automation IO	Automation IO
	Indoor Positioning
Internet Protocol Support (Currently not supported by the SoftDevice)	

**Important:** Examples for selected profiles and services are available in the nRF5 SDK. See the [nRF5 SDK](#) documentation for details.

## 11.2 *Bluetooth*<sup>®</sup> low energy features

The BLE protocol stack in the SoftDevice has been designed to provide an abstract but flexible interface for application development for *Bluetooth*<sup>®</sup> low energy devices.

GAP, GATT, SM, and L2CAP are implemented in the SoftDevice and managed through the API. The SoftDevice implements GAP and GATT procedures and modes that are common to most profiles such as the handling of discovery, connection, data transfer, and bonding.

The BLE API is consistent across *Bluetooth*<sup>®</sup> role implementations where common features have the same interface. The following tables describe the features found in the BLE protocol stack.

**Table 16: API features in the BLE stack**

API features	Description
Interface to: GATT / GAP	Consistency between APIs including shared data formats.
Attribute table sizing, population and access	Full flexibility to size the attribute table at application compile time and to populate it at run time. Attribute removal is not supported.
Asynchronous and event driven	Thread-safe function and event model enforced by the architecture.
Vendor-specific (128-bit) UUIDs for proprietary profiles	Compact, fast and memory efficient management of 128-bit UUIDs.
Packet flow control	Full application control over data buffers to ensure maximum throughput.

**Table 17: GAP features in the BLE stack**

GAP features	Description
Multi-role:	Central, Peripheral, Observer, and Broadcaster can run concurrently with a connection.
Multiple bond support	Keys and peer information stored in application space. No restrictions in stack implementation.
Security Mode 1: Levels 1, 2, 3 & 4	Support for all levels of SM 1.

**Table 18: GATT features in the BLE stack**

GATT features	Description
Full GATT Server	Support for eight concurrent ATT server sessions. Includes configurable Service Changed support.
Support for authorization	Enables control points. Enables freshest data. Enables GAP authorization.
Full GATT Client	Flexible data management options for packet transmission with either fine control or abstract management.
Implemented GATT Sub-procedures	Exchange MTU. Discover all Primary Services. Discover Primary Service by Service UUID. Find included Services. Discover All Characteristics of a Service. Discover Characteristics by UUID. Discover All Characteristic Descriptors. Read Characteristic Value. Read using Characteristic UUID. Read Long Characteristic Values. Read Multiple Characteristic Values (Client only). Write Without Response. Write Characteristic Value. Notifications. Indications. Read Characteristic Descriptors. Read Long Characteristic Descriptors.

GATT features	Description
	Write Characteristic Descriptors. Write Long Characteristic Values. Write Long Characteristic Descriptors. Reliable Writes.

**Table 19: Security Manager (SM) features in the BLE stack**

Security Manager features	Description
Flexible key generation and storage for reduced memory requirements.	Keys are stored directly in application memory to avoid unnecessary copies and memory constraints.
Authenticated MITM (Man in the middle) protection	Allows for per-link elevation of the encryption security level.
Pairing methods: Just works, Numeric Comparison, Passkey Entry and Out of Band	API provides the application full control of the pairing sequences.

**Table 20: Attribute Protocol (ATT) features in the BLE stack**

ATT features	Description
Server protocol	Fast and memory efficient implementation of the ATT server role.
Client protocol	Fast and memory efficient implementation of the ATT client role.
Configurable ATT_MTU size	Allows for per-link configuration of ATT_MTU size.

**Table 21: Controller, Link Layer (LL) features in the BLE stack**

Controller, Link Layer features	Description
Master role Scanner/Initiator roles	The SoftDevice supports eight concurrent master connections and an additional Scanner/Initiator role. When the maximum number of simultaneous connections are established, the Scanner role will be supported for new device discovery. However, the initiator is not available at that time.
Channel map configuration	Setup of channel map for all master connections from the application. Accepting update for the channel map for a slave connection.
Slave role Advertiser/broadcaster role	Supports advertiser, or one peripheral connection and one additional broadcaster.
Master-initiated connection parameter update	Central role may initiate connection parameter update. Peripheral role will accept connection parameter update.

Controller, Link Layer features	Description
LE Data Packet Length Extension (DLE)	Up to 251 bytes of LL data channel packet payload. Both Central and Peripheral roles are able to initiate DLE update procedure, and respond to a peer-initiated DLE update procedure.
Encryption	
RSSI	Signal strength measurements during advertising, scanning, and central and peripheral connections.
LE Ping	
Privacy	The LL can generate and resolve resolvable private addresses in the advertiser, scanner and initiator roles.
Extended Scanner Filter Policies	

**Table 22: Proprietary features in the BLE stack**

Proprietary features	Description
TX Power control	Access for the application to change TX power settings anytime.
Master Boot Record (MBR) for Device Firmware Update (DFU)	Enables over-the-air SoftDevice replacement, giving full SoftDevice update capability.

### 11.3 Limitations on procedure concurrency

When the SoftDevice has established multiple connections as a Central, the concurrency of protocol procedures will have some limitations.

The Host instantiates both GATT and GAP instances for each connection, while the Security Manager (SM) Initiator is only instantiated once for all connections. The Link Layer also has concurrent procedure limitations that are handled inside the SoftDevice without requiring management from the application.

**Table 23: Limitations on procedure concurrency**

Protocol procedures	Limitation with multiple connections
GATT	None. All procedures can be executed in parallel.
GAP	None. All procedures can be executed in parallel. Note that some GAP procedures require link layer control procedures (connection parameter update and encryption). In this case, the GAP module will queue the LL procedures and execute them in sequence.
SM	SM procedures cannot be executed in parallel for connections as a Central. That is, each SM procedure must run to completion before the next procedure begins across all connections as a Central. For example <code>sd_ble_gap_authenticate()</code> .

Protocol procedures	Limitation with multiple connections
LL	<p>The LL Disconnect procedure has no limitations and can be executed on any, or all, links simultaneously.</p> <p>The LL connection parameter update and encryption establishment procedure on a master link can only be executed on one master link at a time.</p> <p>Accepting connection parameter update and encryption establishment on a slave link is always allowed irrespective of any control procedure running on master links.</p>

## 11.4 BLE role configuration

The S132 SoftDevice stack supports concurrent operation in multiple *Bluetooth*<sup>®</sup> low energy roles. The roles available can be configured when the S132 SoftDevice stack is enabled at runtime.

The SoftDevice provides a mechanism for enabling the number of Central or Peripheral roles the application can run concurrently. The SoftDevice can be configured with one connections as a Peripheral and up to eight connections as a Central. The SoftDevice supports running one Advertiser or Broadcaster and one Scanner or Observer concurrently with the BLE connections.

An Initiator can only be started if there are less than eight connections established as a Central. Similarly, a connectable Advertiser can only be started if there are no connections as a Peripheral established. If there is a total of eight connections running, an Advertiser or Broadcaster cannot run simultaneously with a Scanner or Observer.

When the SoftDevice is enabled it will allocate memory for the connections the application has requested. See [SoftDevice memory usage](#) on page 55 chapter for more details.

The SoftDevice supports three predetermined bandwidth levels: low, mid(medium), and high. The bandwidth levels are defined per connection interval, so the connection interval of the connection will also affect the total bandwidth. Bandwidth configuration is an optional feature and if the application chooses to not use the feature the SoftDevice will use default bandwidth configurations. By default, connections as a Central will be set to medium bandwidth and connections as a Peripheral will be set to high bandwidth. The bandwidth can also be configured individually for both transmitting and receiving, allowing for more fine-grained control with asymmetric bandwidth.

When using the bandwidth feature of the SoftDevice the application needs to provide the SoftDevice with information about the bandwidth configurations the application intends to use. This is done when enabling the BLE stack and will allow the SoftDevice to allocate memory pools large enough to fit the bandwidth configurations of all connections. Otherwise connections can fail to be established because there is not enough memory available for the bandwidth requirement of the connection. If the application changes the bandwidth configuration when the link is disconnected it might fail to reconnect because of internal fragmentation of the SoftDevice memory pools. It is therefore recommended to disconnect all links when changing the bandwidth configurations of links.

In addition to the bandwidth feature, connection bandwidth can be increased by enabling Connection Event Length Extension. See [Connection timing with Connection Event Length Extension](#) on page 67 for more information. Enabling Connection Event Length Extension does not increase the size of the SoftDevice memory pools.

Bandwidth and multilink scheduling can both affect each other. See [Scheduling](#) on page 59 for details. Knowledge about multilink scheduling can be used to get predictable performance on all links. Refer [Suggested intervals and windows](#) on page 68 for details about recommended configurations.



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# Chapter 12

## Radio Notification

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The Radio Notification is a configurable feature that enables ACTIVE and INACTIVE (nACTIVE) signals from the SoftDevice to the application notifying it when the radio is in use.

### 12.1 Radio Notification Signals

The Radio Notification signals are sent prior to and at the end of SoftDevice Radio Events or application Radio Events<sup>8</sup>, i.e. defined time intervals of radio operation.

Radio notifications behave differently when Connection Event Length Extension is enabled. [Radio Notification with Connection Event Length Extension](#) on page 48 explains the behavior when this feature is enabled. Otherwise the presented material assumes that the feature is disabled.

To ensure that the Radio Notification signals behave in a consistent way, the Radio Notification shall always be configured when the SoftDevice is in an idle state with no protocol stack or other SoftDevice activity in progress. Therefore, it is recommended to configure the Radio Notification signals directly after the SoftDevice has been enabled.

If it is enabled, the ACTIVE signal is sent before the Radio Event starts. Similarly, if the nACTIVE signal is enabled, it is sent at the end of the Radio Event. These signals can be used by the application developer to synchronize the application logic with the radio activity. For example, the ACTIVE signal can be used to switch off external devices to manage peak current drawn during periods when the radio is ON, or to trigger sensor data collection for transmission during the upcoming Radio Event.

The notification signals are sent using software interrupt, as specified in [Table 5: Allocation of software interrupt vectors to SoftDevice signals](#) on page 20.

As both ACTIVE and nACTIVE use the same software interrupt, it is up to the application to manage them. If both ACTIVE and nACTIVE are configured ON by the application, there will always be an ACTIVE signal before an nACTIVE signal.

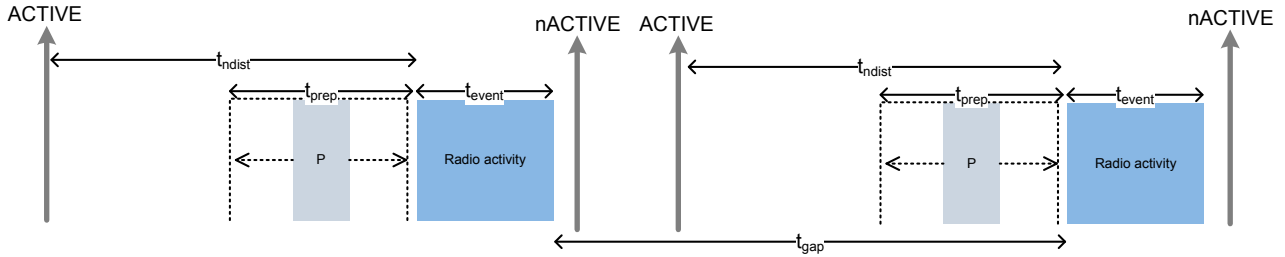
Refer to [Table 24: Notation and terminology for the Radio Notification used in this chapter](#) on page 42 for the notation that is used in this Section.

When there is sufficient time between Radio Events ( $t_{\text{gap}} > t_{\text{ndist}}$ ), both the ACTIVE and nACTIVE notification signals will be present at each Radio Event. [Figure 8: Two radio events with ACTIVE and nACTIVE signals](#) on page 42 illustrates an example of this scenario with two Radio Events. The figure also illustrates the ACTIVE and nACTIVE signals with respect to the Radio Events.

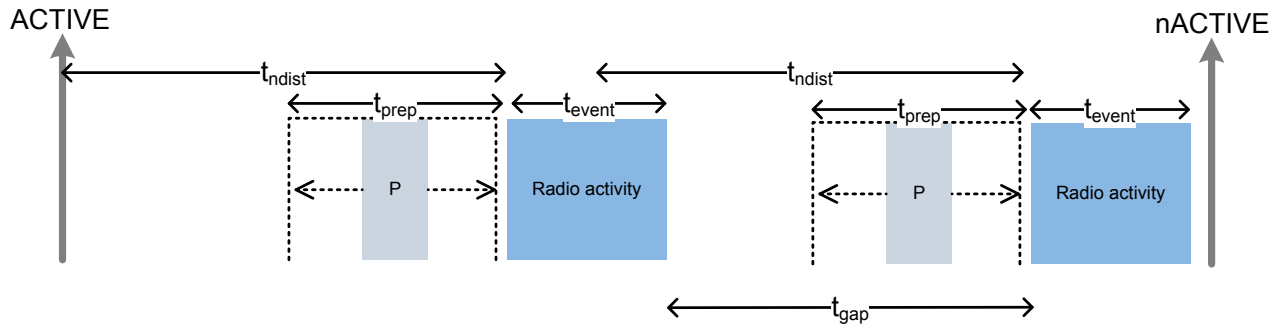
When there is not sufficient time between the Radio Events ( $t_{\text{gap}} < t_{\text{ndist}}$ ), the ACTIVE and nACTIVE notification signals will be skipped. There will still be an ACTIVE signal before the first event, and an nACTIVE signal after the last event. This is shown in [Figure 9: Two radio events where  \$t\_{\text{gap}}\$  is too small and the notification signals will not be available between the events](#) on page 42.

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<sup>8</sup> Application Radio Events are defined as Radio Timeslots, see [Multiprotocol support](#) on page 25.



**Figure 8: Two radio events with ACTIVE and nACTIVE signals**



**Figure 9: Two radio events where  $t_{gap}$  is too small and the notification signals will not be available between the events**

**Table 24: Notation and terminology for the Radio Notification used in this chapter**

Label	Description	Notes
ACTIVE	The ACTIVE signal prior to a Radio Event.	
nACTIVE	The nACTIVE signal after a Radio Event.	Because both ACTIVE and nACTIVE use the same software interrupt, it is up to the application to manage them. If both ACTIVE and nACTIVE are configured ON by the application, there will always be an ACTIVE signal before an nACTIVE signal.
P	SoftDevice CPU processing in interrupt priority level 0 between the ACTIVE signal and the start of the Radio Event.	The CPU processing may occur anytime, up to $t_{prep}$ before the start of the Radio Event.
RX	Reception of packet.	
TX	Transmission of packet.	
$t_{event}$	The total time of a Radio Event.	
$t_{gap}$	The time between the end of one Radio Event and the start of the following one.	
$t_{ndist}$	The notification distance - the time between the ACTIVE signal and the first RX/TX in a Radio Event.	This time is configurable by the application developer.

Label	Description	Notes
$t_{\text{prep}}$	The time before first RX/TX available to the protocol stack to prepare and configure the radio.	The application will be interrupted by a SoftDevice interrupt handler at priority level 0 $t_{\text{prep}}$ time units before the start of the Radio Event.  <b>Important:</b> All packet data to send in an event should have been sent to the stack $t_{\text{prep}}$ before the Radio Event starts.
$t_{\text{p}}$	Time used for preprocessing before the Radio Event.	
$t_{\text{interval}}$	Time period of periodic protocol Radio Events (e.g. BLE connection interval).	
$t_{\text{EEO}}$	Minimum time between central role Radio Events (Event-to-Event Offset).	The minimum time between the start of adjacent central role Radio events, and between the last central role radio event and the scanner. $t_{\text{EEO-CO}}$ can be different for different connections, and it depends on the maximum packet payload size and the bandwidth configuration of the connection. See <a href="#">BLE role configuration</a> on page 40 for more information on the BLE stack configuration. Connection Event Length Extension does not affect $t_{\text{EEO}}$ .
$t_{\text{ScanReserved}}$	Reserved time needed by the SoftDevice for each ScanWindow	

**Table 25: BLE Radio Notification timing ranges**

Value	Range ( $\mu\text{s}$ )
$t_{\text{ndist}}$	800, 1740, 2680, 3620, 4560, 5500 (Configured by the application)
$t_{\text{event}}$	2750 to 5500 - Undirected and scannable advertising, 0 to 31 byte payload, 3 channels 2150 to 2950 - Non-connectable advertising, 0 to 31 byte payload, 3 channels 1.28 seconds - Directed advertising, 3 channels Slave bandwidth LOW : 1700 Slave bandwidth MID : 3650 Slave bandwidth HIGH : 6550 Master bandwidth LOW : 1575 Master bandwidth MID : 3500

Value	Range (µs)
	Master bandwidth HIGH : 6375 Note: Master and Slave $t_{event}$ values are for full duplex transfer of 27 byte long packets, Connection Event Length Extension disabled.
$t_{prep}$	167 to 1542
$t_p$	$\leq 165$
$t_{EEO}$	Bandwidth LOW : 1750 Bandwidth MID : 3700 Bandwidth HIGH : 6560 Note: These values are for full duplex transfer of 27 byte long packets.
$t_{ScanReserved}$	760

Based on the numbers from [Table 25: BLE Radio Notification timing ranges](#) on page 43, the amount of CPU time available to the application between the ACTIVE signal and the start of the Radio Event is:

$$t_{ndist} - t_p$$

The following expression shows the length of the time interval between the ACTIVE signal and the stack prepare interrupt:

$$t_{ndist} - t_{prep(maximum)}$$

If the data packets are to be sent in the following Radio Event, they must be transferred to the stack using the protocol API within this time interval.

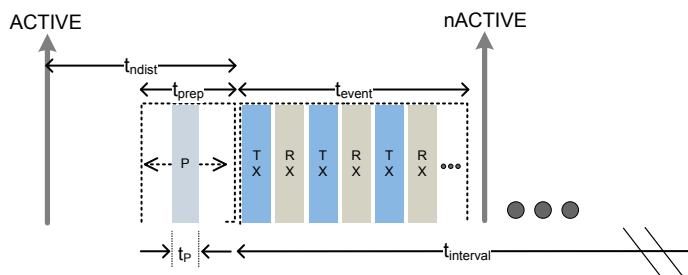
**Important:**  $t_{prep}$  may be greater than  $t_{ndist}$  when  $t_{ndist} = 800$ . If time is required to handle packets or manage peripherals before interrupts are generated by the stack,  $t_{ndist}$  must be set larger than 1550.

## 12.2 Radio Notification on connection events as a Central

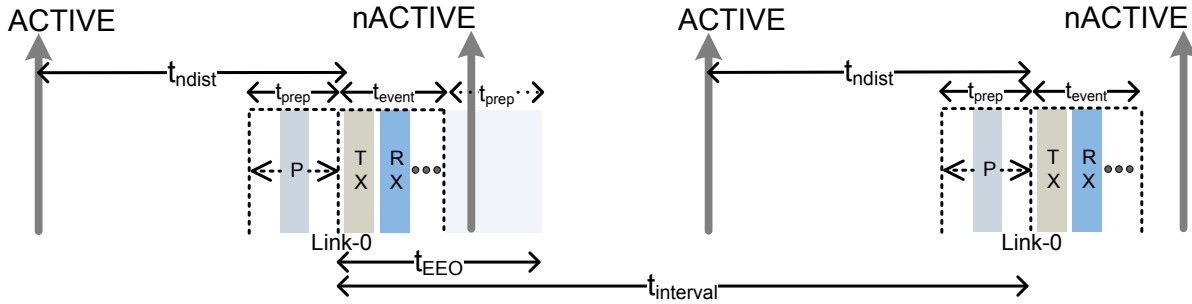
This section clarifies the functionality of the Radio Notification feature when the SoftDevice operates as a Central. The behavior of the notification signals is shown under various combinations of active central links and scanning events.

Refer to [Table 24: Notation and terminology for the Radio Notification used in this chapter](#) on page 42 for the notations used in the text and the figures of this section. For a comprehensive understanding of role scheduling see [Scheduling](#) on page 59.

For a central link multiple packets may be exchanged within a single Radio (connection) Event. This is shown in [Figure 10: A BLE central link with multiple packet exchange per connection event](#) on page 44.



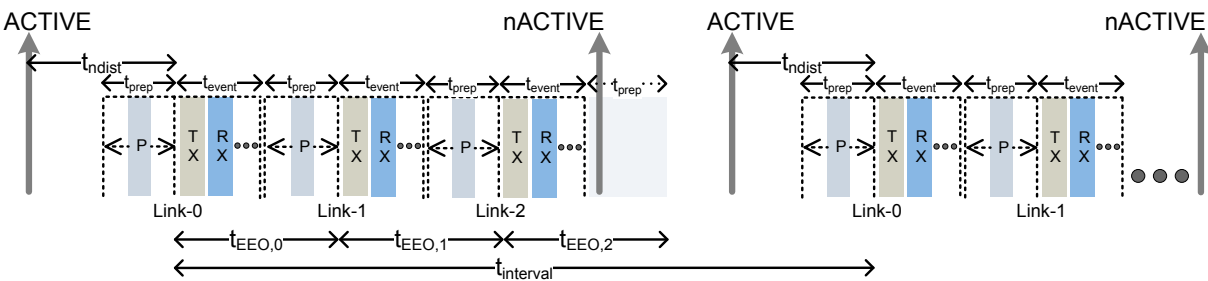
**Figure 10: A BLE central link with multiple packet exchange per connection event**



**Figure 11: BLE Radio Notification signal in relation to a single active link**

To ensure that the ACTIVE notification signal will be available to the application at the configured time when a single central link is established (Figure 11: BLE Radio Notification signal in relation to a single active link on page 45), the following condition must hold:

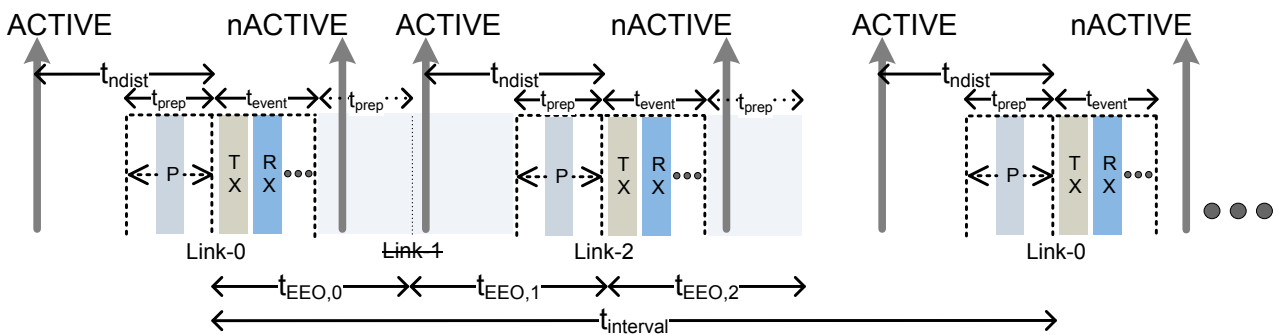
$$t_{ndist} + t_{EEO} - t_{prep} < t_{interval}$$



**Figure 12: BLE Radio Notification signal in relation to 3 active links**

A SoftDevice operating as a Central may establish multiple central links and schedule them back-to-back in each connection interval. An example of a Central with 3 links is shown in Figure 12: BLE Radio Notification signal in relation to 3 active links on page 45). To ensure that the ACTIVE notification signal will be available to the application at the configured time when 3 links are established as a Central, the following condition must hold:

$$t_{ndist} + t_{EEO,0} + t_{EEO,1} + t_{EEO,2} - t_{prep} < t_{interval}$$



**Figure 13: BLE Radio Notification signal when the number of active links as a Central is 2**

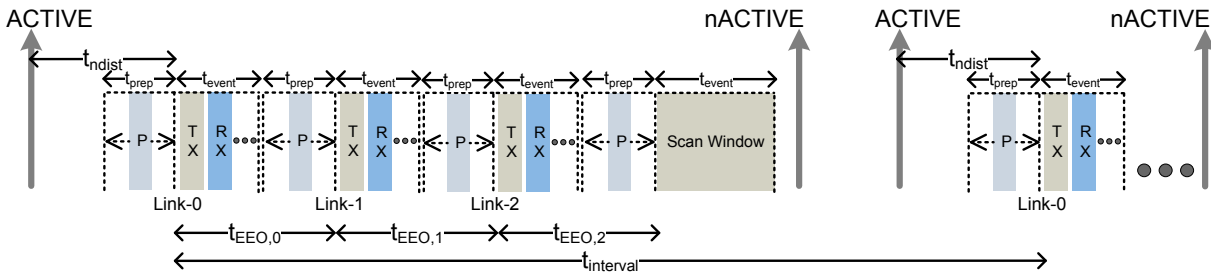
In case one or several central links are dropped, an idle time interval will exist between active central links. If the interval is sufficiently long, the application may unexpectedly receive the Radio Notification signal. In particular, the notification signal will be available to the application in the idle time interval, if this interval is longer than  $t_{ndist}$ . This can be expressed as:

$$\sum_{i=m, \dots, n} t_{EEO,i} + t_{prep} > t_{ndist} \text{ where Link-}m, \dots, \text{Link-}n \text{ are consecutive inactive central links.}$$

For example, in the scenario shown in Figure 13: BLE Radio Notification signal when the number of active links as a Central is 2 on page 45 Link-1 is not active, a gap of  $t_{EEO,1}$  time units (e.g. ms) exists between Link-0

and Link-2. Consequently, the ACTIVE notification signal will be available to the application, if the following condition holds:

$$t_{EEO,1} + t_{prep} > t_{ndist}$$



**Figure 14: BLE Radio Notification signal in relation to 3 active connections as a Central while scanning**

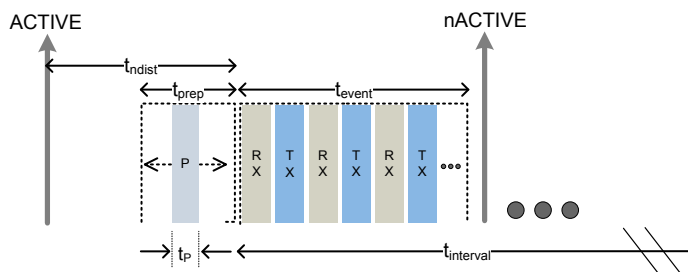
A SoftDevice may, additionally, run a scanner in parallel to the central links. This is shown in [Figure 14: BLE Radio Notification signal in relation to 3 active connections as a Central while scanning](#) on page 46, where 3 central links and a scanner have been established. To guarantee in this case that the ACTIVE notification signal will be available to the application at the configured time, the following condition must hold:

$$t_{ndist} + t_{EEO,0} + t_{EEO,1} + t_{EEO,2} + \text{Scan Window} + t_{ScanReserved} < t_{interval}$$

### 12.3 Radio Notification on connection events as a Peripheral

Similar to central links, peripheral links may also include multiple packet exchange within a single Radio (connection) Event.

Radio Notification events are as shown in [Figure 15: A BLE peripheral link with multiple packet exchange per connection event](#) on page 46.

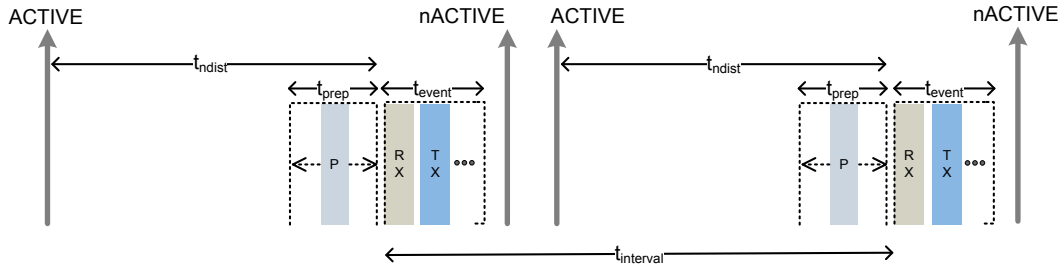


**Figure 15: A BLE peripheral link with multiple packet exchange per connection event**

To guarantee that the ACTIVE notification signal is available to the application at the configured time when a single peripheral link is established, the following condition must hold (with one exception, see [Table 26: Maximum Peripheral packet transfer per BLE Radio Event for given combinations of Radio Notification distances and connection intervals](#) on page 47):

$$t_{ndist} + t_{event} < t_{interval}$$

The SoftDevice will limit the length of a Radio Event ( $t_{event}$ ), thereby reducing the maximum number of packets exchanged, to accommodate the selected  $t_{ndist}$ . [Figure 16: Consecutive peripheral Radio Events with BLE Radio Notification signals](#) on page 47 shows consecutive Radio Events with Radio Notification signal and illustrates the limitation in  $t_{event}$  which may be required to guarantee  $t_{ndist}$  is preserved.



**Figure 16: Consecutive peripheral Radio Events with BLE Radio Notification signals**

Table 26: Maximum Peripheral packet transfer per BLE Radio Event for given combinations of Radio Notification distances and connection intervals on page 47 shows the limitation on the maximum number of 27 bytes long packets which can be transferred per Radio Event for given combinations of t<sub>ndist</sub> and t<sub>interval</sub>.

**Table 26: Maximum Peripheral packet transfer per BLE Radio Event for given combinations of Radio Notification distances and connection intervals**

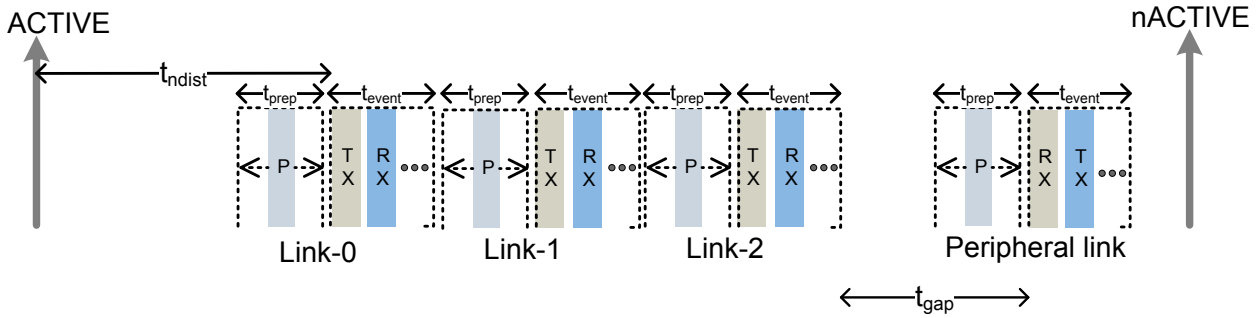
The data in this table assumes 27 bytes long packets and full-duplex, HIGH/HIGH BLE bandwidth configuration, Connection Event Length Extension disabled.

t <sub>ndist</sub>	t <sub>interval</sub>		
	7.5 ms	10 ms	≥ 15 ms
800	6	6	6
1740	5	6	6
2680	4	6	6
3620	3	5	6
4560	2	4	6
5500	1	4	6

## 12.4 Radio Notification with concurrent Peripheral and central connection events

A peripheral link is arbitrarily positioned with respect to the central links. Therefore, if the peripheral connection event occurs too close to the central connection event, the notification signal before the peripheral connection event might not be available to the application.

Figure 17: Example: The gap between the links as a Central and the Peripheral is too small to trigger the notification signal on page 48 shows an example where the time distance between the central and the peripheral events is too small to allow the SoftDevice to trigger the ACTIVE notification signal.

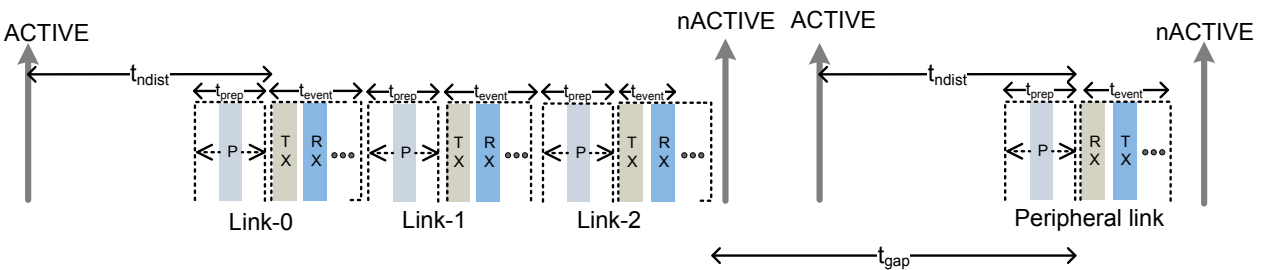


**Figure 17: Example: The gap between the links as a Central and the Peripheral is too small to trigger the notification signal**

If the following condition is met:

$$t_{gap} > t_{ndist}$$

the notification signal will arrive, as illustrated in [Figure 18: Example: The gap between the links as a Central and the Peripheral is sufficient to trigger the notification signal](#) on page 48.



**Figure 18: Example: The gap between the links as a Central and the Peripheral is sufficient to trigger the notification signal**

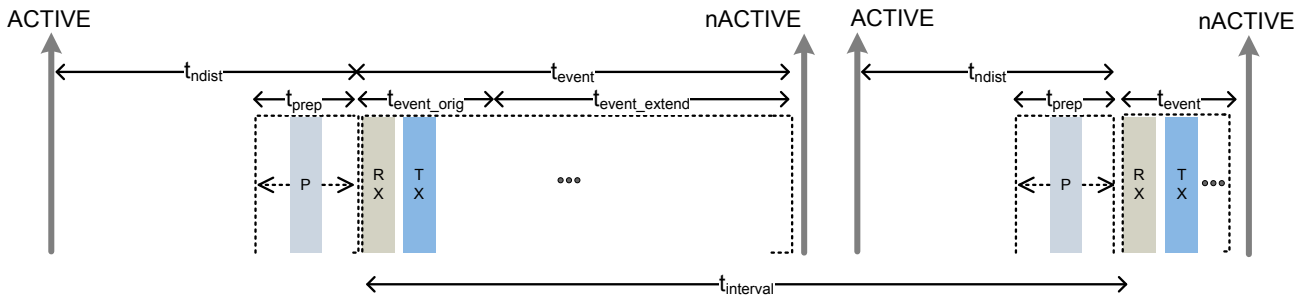
## 12.5 Radio Notification with Connection Event Length Extension

This section clarifies the functionality of the Radio Notification signal when Connection Event Length Extension is enabled in the SoftDevice.

When Connection Event Length Extension is enabled, connection events may be extended beyond their initial  $t_{event}$ , to accommodate the exchange of a higher number of packet pairs. This allows more idle time to be used by the radio and will consequently affect the radio notifications.

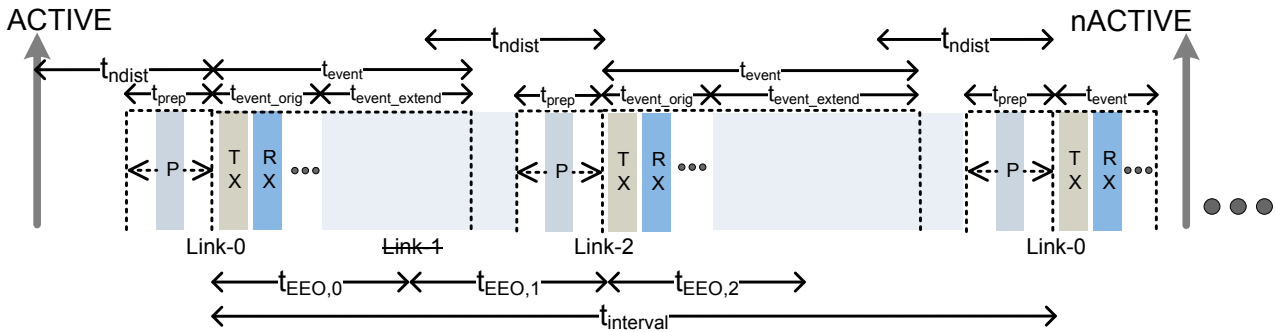
In peripheral links, the SoftDevice will impose a limit on how long the Radio Event ( $t_{event}$ ) may be extended, thereby restricting the maximum number of packets exchanged, to accommodate the selected  $t_{ndist}$ . [Figure 19: Example: Extending the peripheral connection event is limited by the Radio Notification](#) on page 49 shows consecutive Radio Events with Radio Notification signal and illustrates that the limitation in extending  $t_{event}$  may be required to guarantee  $t_{ndist}$  is preserved.





**Figure 19: Example: Extending the peripheral connection event is limited by the Radio Notification**

In central links, Radio Notification does not impose limits on how long the Radio event ( $t_{event}$ ) may be extended. This implies that all idle time in between connection events can be used for event extension. As a result of this the ACTIVE signal and nACTIVE signals between connection events cannot be guaranteed when Connection Event Length Extension is enabled. [Figure 20: Example: The gaps between links as centrals are used to extend the connection events of the links.](#) on page 49 shows the idle time can be used by the central links when Connection Event Length Extension is enabled.



**Figure 20: Example: The gaps between links as centrals are used to extend the connection events of the links.**

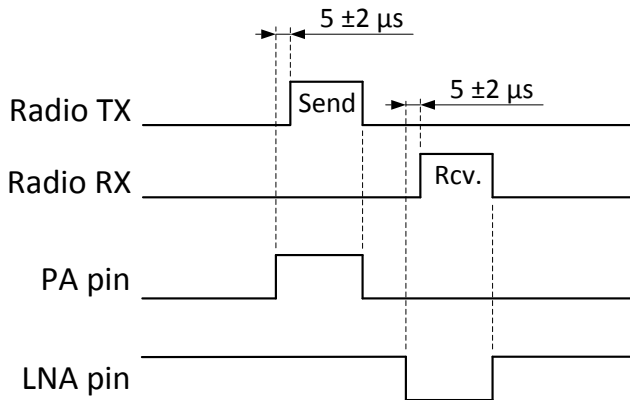
When a central and a peripheral link are running concurrently, the central connection event may be extended to utilize the available time until the start of the peripheral connection event. In case the central event ends sufficiently close to the start of the peripheral event, the notification signal before the peripheral connection event may not be available to the application. [Figure 17: Example: The gap between the links as a Central and the Peripheral is too small to trigger the notification signal](#) on page 48 shows an example where the time distance between the central and the peripheral events is too small to allow the SoftDevice to trigger the ACTIVE notification signal.

## 12.6 Power Amplifier and Low Noise Amplifier control configuration (PA/LNA)

The SoftDevice can be configured by the application to toggle GPIO pins before and after radio transmission and before and after radio reception to control a Power Amplifier and/or a Low Noise Amplifier (PA/LNA).

The PA/LNA control functionality is provided by the SoftDevice protocol stack implementation and must be enabled by the application before it can be used.

**Important:** In order to be used along with proprietary radio protocols that make use of the Timeslot API, the PA/LNA control functionality needs to be implemented as part of the proprietary radio protocol stack.



**Figure 21: Example of timings when PA/LNA control is enabled. The PA pin is configured active high, and the LNA pin is configured active low.**

The PA and the LNA are controlled by one GPIO pin each, which are activated, respectively, during radio transmission and radio reception. The pins can be configured to be active low or active high. The SoftDevice will guarantee that the pins will be set to active  $5 \pm 2 \mu\text{s}$  before the EVENTS\_READY signal on the RADIO using a GPIOTE connected with a PPI channel to a timer. The selected time difference allows for a sufficient ramp up time for the amplifiers, while it avoids activating them too early during the radio start up procedure (which results in amplifying carrier noise etc.). The pins are restored to inactive state using a PPI connected to the EVENTS\_DISABLED event on the RADIO. See [nRF52832 Product Specification](#) for more details on the nRF52 RADIO notification signals.

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## Chapter 13

# Master Boot Record and bootloader

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The SoftDevice supports the use of a bootloader. A bootloader may be used to update the firmware on the SoC.

The nRF52 software architecture includes a Master Boot Record (MBR) ( [Figure 1: System on Chip application with the SoftDevice](#) on page 10). The MBR is necessary in order for the bootloader to update the SoftDevice, or to update the bootloader itself. The MBR is a required component in the system. The inclusion of a bootloader is optional.

### 13.1 Master Boot Record

The main functionality of the MBR is to provide an interface to allow in-system updates of the SoftDevice and bootloader firmware.

The Master Boot Record (MBR) module occupies a defined region in the SoC program memory where the System Vector table resides.

All exceptions (reset, hard fault, interrupts, SVC) are, first, processed by the MBR and then are forwarded to the appropriate handlers (for example the bootloader or the SoftDevice exception handlers). See [Interrupt model and processor availability](#) on page 70 for more details on the interrupt forwarding scheme.

During a firmware update process, the MBR is never erased. The MBR ensures that the bootloader can recover from any unexpected resets during an ongoing update process.

In order to issue the `SD_MBR_COMMAND_COPY_BL` or `SD_MBR_COMMAND_VECTOR_TABLE_BASE_SET` commands to the MBR, the `UICR.NRFFW[1]` register must be set to an address (MBRPARAMADDR address in [Figure 22: MBR, SoftDevice and bootloader architecture](#) on page 52 ) corresponding to a page in the Application Flash Region (see [Memory isolation and runtime protection](#) on page 13). If `UICR.NRFFW[1]` is not set the commands will return `NRF_ERROR_NO_MEM`. This page will be cleared by the MBR and used to store parameters before chip reset. When the `UICR.NRFFW[1]` register is set, the page it refers to must not be used by the application. If the application does not want to reserve a page for the MBR parameters, it must leave the `UICR.NRFFW[1]` register to `0xFFFFFFFF` (its default value).

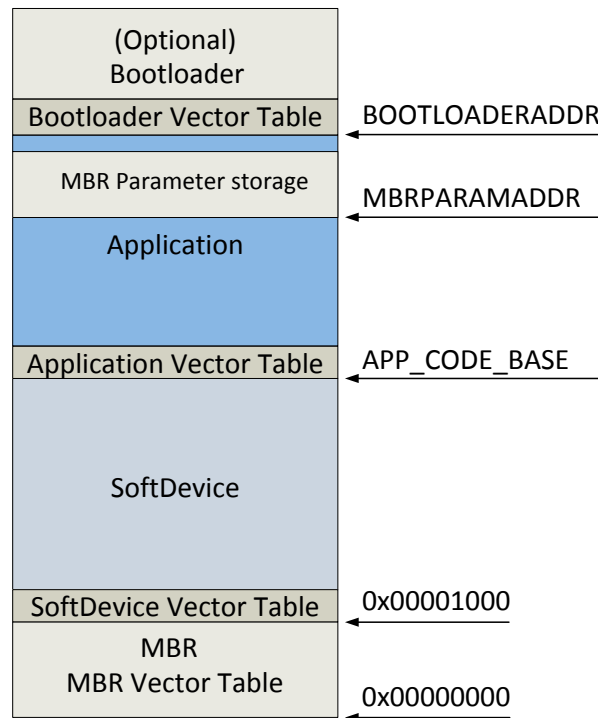
### 13.2 Bootloader

A bootloader may be used to handle in-system update procedures.

The bootloader has full access to the SoftDevice API and can be implemented like any application that uses the SoftDevice. In particular, the bootloader can make use of the SoftDevice API for BLE communication.

The bootloader is supported in the SoftDevice architecture by using a configurable base address for the bootloader in the application Flash Region. The base address (`BOOTLOADERADDR`) is configured by setting the `UICR.NRFFW[0]` register. The bootloader is responsible for determining the start address of the application. It uses `sd_softdevice_vector_table_base_set(uint32_t address)` to tell the SoftDevice where the application starts.

The bootloader is also responsible for keeping track of, and verifying the integrity of the SoftDevice. If an unexpected reset occurs during an update of the SoftDevice, it is the responsibility of the bootloader to detect this and resume the update procedure.



**Figure 22: MBR, SoftDevice and bootloader architecture**

### 13.3 Master Boot Record (MBR) and SoftDevice reset procedure

Upon system reset, execution branches to the MBR Reset Handler as specified in the System Vector Table.

The MBR and SoftDevice reset behavior is as follows:

- If an in-system bootloader update procedure is in progress:
  - The in-system update procedure continues its execution.
  - System resets.
- Else if `SD_MBR_COMMAND_VECTOR_TABLE_BASE_SET` has been called previously:
  - Forward interrupts to the address specified in the `sd_mbr_command_vector_table_base_set_t` parameter of the `SD_MBR_COMMAND_VECTOR_TABLE_BASE_SET` command.
  - Run from Reset Handler (defined in the vector table which is passed as command parameter).
- Else if a bootloader is present:
  - Forward interrupts to the bootloader.
  - Run Bootloader Reset Handler (defined in bootloader Vector Table at `BOOTLOADERADDR`).
- Else if a SoftDevice is present:
  - Forward interrupts to the SoftDevice.
  - Execute the SoftDevice Reset Handler (defined in SoftDevice Vector Table at `0x00001000`).
  - In this case, `APP_CODE_BASE` is hardcoded inside the SoftDevice.
  - The SoftDevice invokes the Application Reset Handler (as specified in the Application Vector Table at `APP_CODE_BASE`).
- Else system startup error:
  - Sleep forever.

## 13.4 Master Boot Record (MBR) and SoftDevice initialization procedure

The SoftDevice can be enabled by the bootloader.

The bootloader can enable the SoftDevice through the following step-by-step procedure:

1. Issuing a command for MBR to forward interrupts to the SoftDevice using `sd_mbr_command()` with `SD_MBR_COMMAND_INIT_SD`.
2. Issuing a command for the SoftDevice to forward interrupts to the bootloader using `sd_softdevice_vector_table_base_set(uint32_t address)` with `BOOTLOADERADDR` as parameter.
3. Enabling the SoftDevice using `sd_softdevice_enable()`.

The bootloader can transfer the execution from itself to the application through the following step-by-step procedure:

1. Issuing a command for MBR to forward interrupts to the SoftDevice using `sd_mbr_command()` with `SD_MBR_COMMAND_INIT_SD`, if interrupts are not forwarded to the SoftDevice.
2. Issuing `sd_softdevice_disable()`, to ensure that the SoftDevice is disabled.
3. Issuing a command for the SoftDevice to forward interrupts to the application using `sd_softdevice_vector_table_base_set(uint32_t address)` with `APP_CODE_BASE` as a parameter.
4. Branching to the application Reset Handler as specified in the Application Vector Table.

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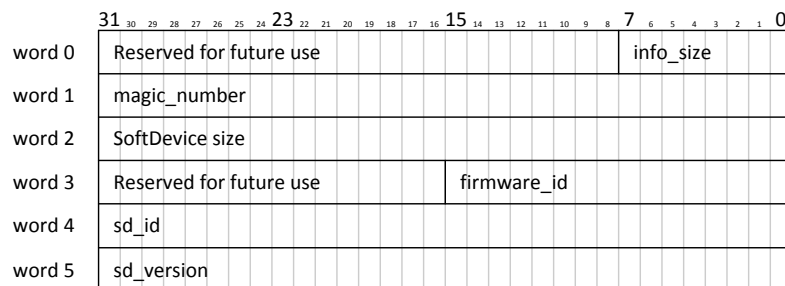
# Chapter 14

## SoftDevice information structure

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The SoftDevice binary file contains an information structure.

The structure is illustrated in [Figure 23: SoftDevice information structure](#) on page 54. The location of the structure, the SoftDevice size, and the `firmware_id` can be obtained at run time by the application using macros defined in the `nrf_sdm.h` header file. The information structure can also be accessed by parsing the binary SoftDevice file.



**Figure 23: SoftDevice information structure**

# Chapter 15

## SoftDevice memory usage

The SoftDevice shares the available flash memory and RAM on the nRF52 SoC with the application. The application must therefore be aware of the memory resources needed by the SoftDevice and leave the parts of the memory used by the SoftDevice undisturbed for correct SoftDevice operation.

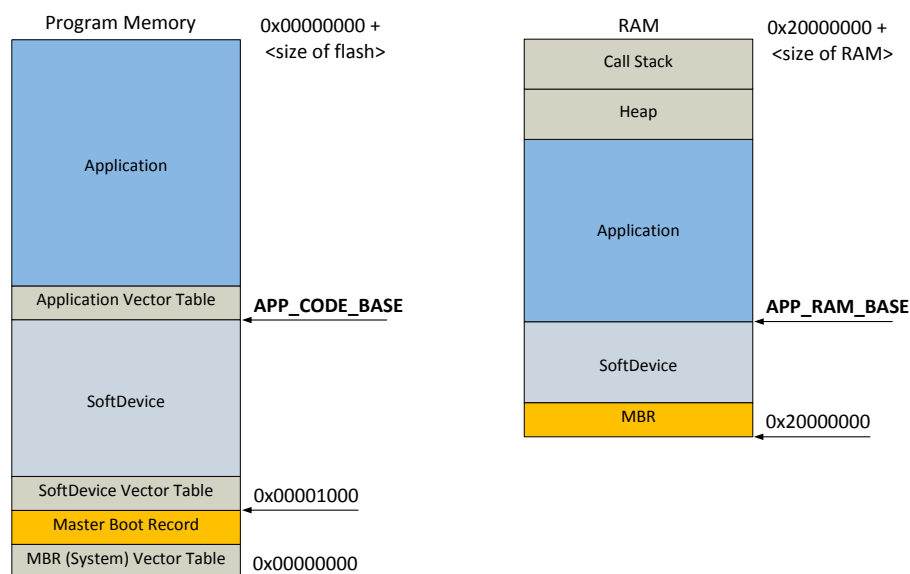
The SoftDevice requires a fixed amount of flash memory and RAM, which are detailed in [Table 27: S132 Memory resource requirements for flash](#) on page 56 and [Table 28: S132 Memory resource requirements for RAM](#) on page 56. In addition, depending on the runtime configuration, the SoftDevice will require:

- Additional RAM for *Bluetooth*<sup>®</sup> low energy (BLE) roles and bandwidth (see [Role configuration](#) on page 57)
- Attributes (see [Attribute table size](#) on page 57)
- Security (see [Security configuration](#) on page 57)
- UUID storage (see [Vendor specific UUID counts](#) on page 57)

### 15.1 Memory resource map and usage

The memory map for program memory and RAM when the SoftDevice is enabled is described in this section.

[Figure 24: Memory resource map](#) on page 55 illustrates the memory usage of the SoftDevice alongside an user application. The flash memory for the SoftDevice is always reserved and the application program code should be placed above the SoftDevice at `APP_CODE_BASE`. The SoftDevice uses the first 8 bytes of RAM when not enabled. Once enabled, the RAM usage of the SoftDevice increases: the RAM requirements of an enabled SoftDevice are detailed in [Table 28: S132 Memory resource requirements for RAM](#) on page 56. With the exception of the call stack, the RAM usage for the SoftDevice is always isolated from the application usage; thus the application is required to not access the RAM region below `APP_RAM_BASE`. The value of `APP_RAM_BASE` is obtained by calling `sd_softdevice_enable`, which will always return the required minimum start address of the application RAM region for the given configuration. An access below the required minimum application RAM start address will result in undefined behavior, see [Table 28: S132 Memory resource requirements for RAM](#) on page 56 for minimum RAM requirements.



**Figure 24: Memory resource map**

### 15.1.1 Memory resource requirements

The tables below show the memory resource requirements both when the S132 SoftDevice is enabled and disabled.

#### Flash

**Table 27: S132 Memory resource requirements for flash**

Flash	Value
Required by the SoftDevice	120 kB <sup>9</sup>
Required by the MBR	4 kB
APP_CODE_BASE address (absolute value)	0x0001F000

#### RAM

**Table 28: S132 Memory resource requirements for RAM**

RAM	S132 Enabled	S132 Disabled
Required by the SoftDevice (in bytes)	0x1348 + Configurable Resources Minimum: 0x19c0 (6592)	8
APP_RAM_BASE address (minimum required value)	0x20000000 + SoftDevice RAM consumption Minimum: 0x200019c0	0x20000008

#### Call stack

By default, the nRF52 SoC will have a shared call stack with both application stack frames and SoftDevice stack frames, managed by the main stack pointer (MSP).

The call stack configuration is done by the application, and the MSP gets initialized on reset to the address specified by the application vector table entry 0. The application may, in its reset vector, configure the CPU to use the process stack pointer (PSP) in thread mode. This configuration is optional but may be required by an operating system (OS); for example, to isolate application threads and OS context memory. The application programmer must be aware that the SoftDevice will use the MSP as it is always executed in exception mode.

**Important:** It is customary, but not required, to let the stack run downwards from the upper limit of the RAM Region.

With each release of an nRF52 SoftDevice, its maximum (worst case) call stack requirement may be updated. The SoftDevice uses the call stack when SoftDevice interrupt handlers execute. These are asynchronous to the application, so the application programmer must reserve call stack for the application in addition to the call stack requirement by the SoftDevice.

The application must reserve sufficient space to satisfy both the application and the nRF52 SoftDevice stack memory requirements. The nRF52 SoC has no designated hardware for detecting stack overflow. The application can use the ARM<sup>®</sup>Cortex<sup>®</sup>-M4 MPU to implement a mechanism for stack overflow detection.

The SoftDevice does not use the ARM<sup>®</sup>Cortex<sup>®</sup>-M4 Floating-point Unit (FPU) and does not configure any floating-point registers. [Table 29: S132 Memory resource requirements for call stack](#) on page 57 depicts the maximum call stack size that may be consumed by the SoftDevice when not using the FPU.

<sup>9</sup> 1 kB = 1024 bytes



Note that the SoftDevice uses multiple interrupt levels, as described in detail in [Interrupt model and processor availability](#) on page 70. If FPU is used by the application, the processor will need to reserve memory in the stack frame for stacking the FPU registers, for each interrupt level used by the SoftDevice. This must be accounted for when configuring the total call stack size. For more information on how the use of multiple interrupt levels impacts the stack size when using the FPU, refer to the ARM<sup>®</sup> Cortex<sup>®</sup>-M4 processor with FPU documentation, Application Note 298.

**Table 29: S132 Memory resource requirements for call stack**

Call stack	S132 Enabled	S132 Disabled
Maximum usage with FPU disabled	1536 bytes (0x600)	0 bytes

## Heap

There is no heap required by nRF52 SoftDevices. The application is free to allocate and use a heap without disrupting the SoftDevice functionality.

## 15.2 Attribute table size

The size of the attribute table can be configured through the SoftDevice API when enabling the BLE stack.

The attribute table size, `ATTR_TAB_SIZE`, has a default value of 0x580 bytes. Applications that require an attribute table smaller or bigger than the default size can choose to either reduce or increase the attribute table size: the minimum attribute table size is 0xD8 bytes. The amount of RAM reserved by the SoftDevice, and the minimum required start address for the application RAM, `APP_RAM_BASE`, will then change accordingly.

For more information on how to configure the attribute table size, refer to the [S132 SoftDevice API](#).

## 15.3 Role configuration

The SoftDevice allows the number of connections, the configuration of each connection and its role to be specified by the application.

Role configuration (the number of connections, their role, max ATT\_MTU and bandwidth configuration) will determine the amount of RAM resources used by the SoftDevice. The minimum required start address for the application RAM, `APP_RAM_BASE`, will change accordingly. See [BLE role configuration](#) on page 40 for more details on role configuration.

## 15.4 Security configuration

The SoftDevice allows the number of security manager protocol (SMP) instances available for all connections operating in central role to be specified by the application.

At least one SMP instance is needed in order to carry out SMP operations for central role connections, and an SMP instance can be shared amongst multiple central role connections. A larger number of SMP instances will allow multiple connections to have ongoing concurrent SMP operations, but this will result in increased RAM usage by the SoftDevice. The number of SMP instances is specified through the `ble_gap_enable_params_t` type on `sd_ble_enable`.

## 15.5 Vendor specific UUID counts

The SoftDevice allows the use of vendor specific UUIDs, which are stored by the SoftDevice in the RAM that is allocated once the SoftDevice is enabled.

The number of vendor specific UUIDs that can be stored by the SoftDevice is set through `ble_common_enable_params_t` type on `sd_ble_enable`. The minimum number of vendor specific UUID count can be 1, whereas the default value is 10.

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# Chapter 16

## Scheduling

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The S132 stack has multiple activities, called timing-activities, which require exclusive access to certain hardware resources. These timing-activities are time multiplexed to give them the required exclusive access for a period of time, this is called a timing-event. Such timing-activities are BLE role events (central roles, peripheral roles), Flash memory API usage, and Radio Timeslot API timeslots.

If timing-events collide, their scheduling is determined by a priority system. If timing-activity A needs a timing-event at a time that overlaps with timing-activity B, and timing-activity A has higher priority, timing-activity A will get the timing-event. Activity B will be blocked and its timing-event will be rescheduled for a later time. If both timing-activity A and timing-activity B have same priority, the timing-activity which was requested first will get the timing-event.

The timing-activities run to completion and cannot be preempted by other timing-activities, even if the timing-activity trying to preempt has a higher priority. This is the case, for example, when timing-activity A and timing-activity B request timing-event at overlapping time with the same priority, and timing-activity A gets the timing-event because it requested it earlier than timing-activity B. If timing-activity B increased its priority and requested again, it would only get the timing-event if timing-activity A had not already started and there was enough time to change the timing-event schedule.

### 16.1 SoftDevice timing-activities and priorities

The SoftDevice supports up to eight connections as a central, up to one connection as a peripheral, an advertiser or broadcaster and an observer or scanner simultaneously. In addition to these BLE roles, Flash memory API and Radio Timeslot API can also run simultaneously.

An Initiator can only be started if there are less than eight connections established as a central. Similarly, a connectable advertiser can only be started if there is no connection as a peripheral established. See [BLE role configuration](#) on page 40 for more information on the BLE stack configuration.

Central link timing-events are added relative to already running central link timing-events. Advertiser and broadcaster timing-events are scheduled as early as possible. Peripheral link timing-events follow the timings dictated by the connected peer. Peripheral role timing-events (Peripheral link timing-event, Advertiser/Broadcaster timing-event) and central role timing-events (Central link timing-event, Initiator/Scanner timing-event) are scheduled independently and so may occur at the same time and collide. Similarly, Flash access timing-event and Radio Timeslot timing-event are scheduled independently and so may occur at the same time and collide.

The different timing-activities have different priorities at different times, dependent upon their state. As an example, if a connection as a peripheral is close to its supervision time-out it will block all other timing-activities and get the timing-event it requests. In this case all other timing-activities will be blocked if they overlap with the connection timing-event, and they will have to be rescheduled. Table [Table 30: Scheduling priorities](#) on page 59 summarizes the priorities:

**Table 30: Scheduling priorities**

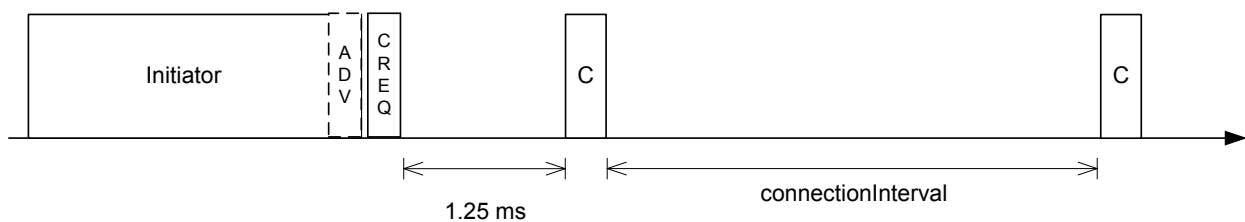
Priority (Decreasing order)	Role state
First priority	<ul style="list-style-type: none"><li>• Connection as a peripheral during connection update procedure.</li><li>• Connection setup as a peripheral (waiting for ack from peer)</li></ul>

Priority (Decreasing order)	Role state
	<ul style="list-style-type: none"> <li>• Connection as a peripheral that is about to time-out</li> </ul>
Second priority	<ul style="list-style-type: none"> <li>• Central connections that are about to time out</li> </ul>
Third priority	<ul style="list-style-type: none"> <li>• Central connection setup (waiting for ack from peer)</li> <li>• Initiator</li> <li>• Advertiser/Broadcaster/Scanner which has been blocked consecutively for a few times.</li> </ul> <p><b>Important:</b> An advertiser which is started while a link as a peripheral is active, does not increase its priority at all.</p>
Fourth priority	<ul style="list-style-type: none"> <li>• All BLE roles in states other than above run with this priority.</li> <li>• Flash access after it has been blocked consecutively for a few times.</li> <li>• Radio Timeslot with high priority.</li> </ul>
Last priority	<ul style="list-style-type: none"> <li>• Flash access</li> <li>• Radio Timeslot with normal priority</li> </ul>

## 16.2 Initiator timing

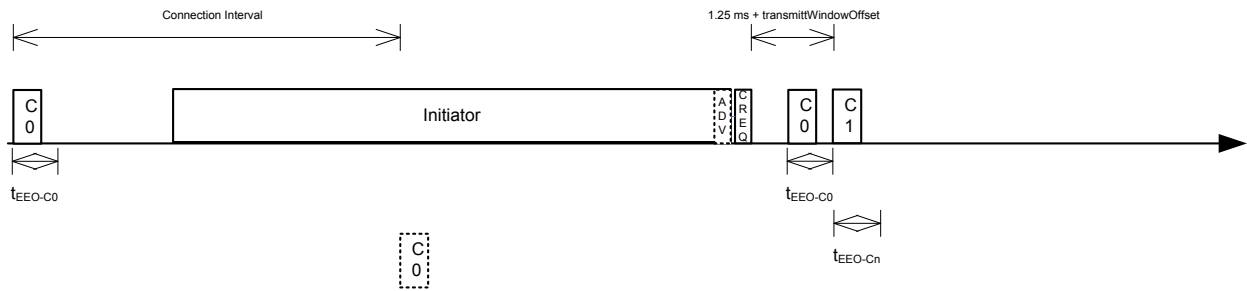
This section introduces the different situations that happen with the initiator when establishing a connection.

When establishing a connection with no other connections active, the initiator will establish the connection in the minimum time and allocate the first Central link connection event 1.25 ms after the connect request was sent, as shown in [Figure 25: Initiator - first connection](#) on page 60.



**Figure 25: Initiator - first connection**

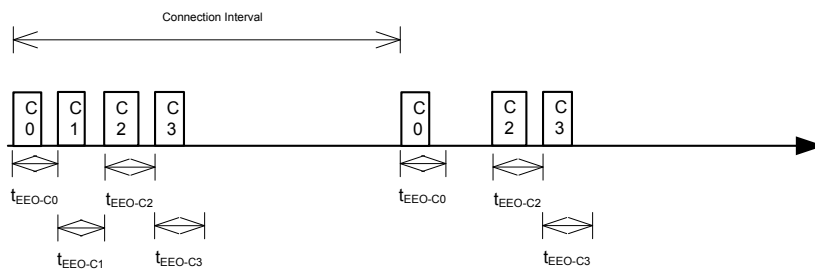
When establishing a new connection with other connections already made as a central, the initiator will start asynchronously to the connected link timing-events and position the new Central connection's first timing-event in any free time between existing central timing-events or after the existing central timing-events. Central link timing-events will be placed close to each other (without any free time between them). This minimum time between start of two central role timing-event is referred as  $t_{EEO}$ .  $t_{EEO}$  is proportional to the payload size and the number of packets exchanged (bandwidth configuration) in timing-event, because more time is required to exchange more and larger packets. Refer to [Table 25: BLE Radio Notification timing ranges](#) on page 43 for  $t_{EEO}$  timing ranges. [Figure 26: Initiator - one central connection running](#) on page 61 illustrates the case of establishing a new central connection with one central connection already running.



**Figure 26: Initiator - one central connection running**

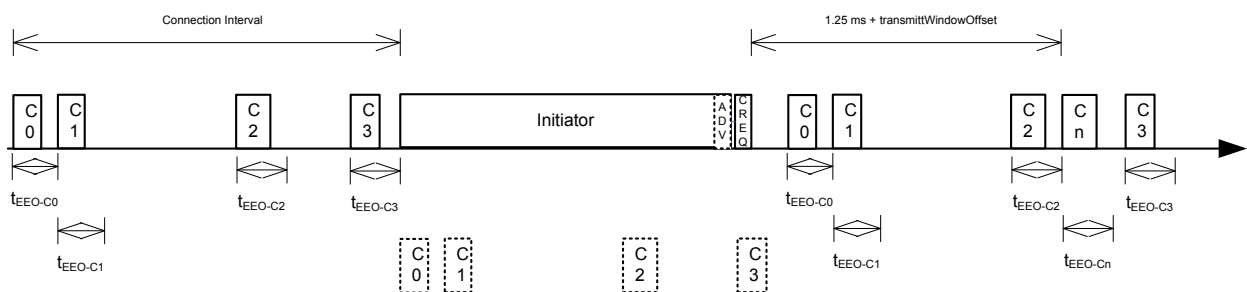
**Important:** The initiator is scheduled asynchronously to any other role (and any other timing-activity) and assigned higher priority to ensure faster connection setup.

When a central link disconnects, the timings of other central link timing-events remain unchanged. [Figure 27: Initiator - free time due to disconnection](#) on page 61 illustrates the case when central link C1 is disconnected, which results in free time between C0 and C2.



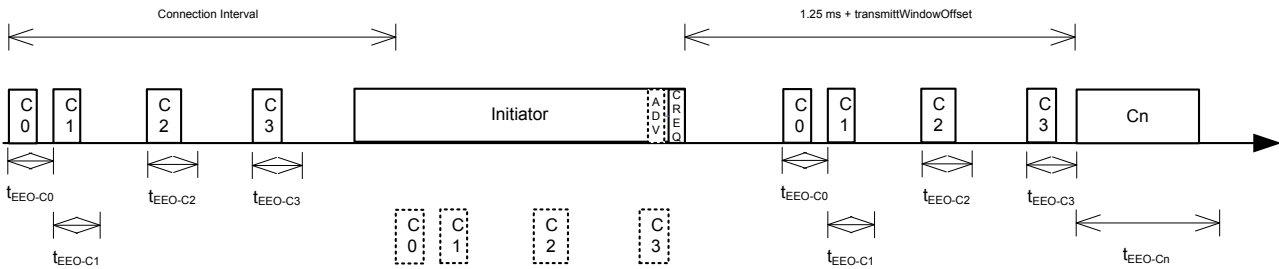
**Figure 27: Initiator - free time due to disconnection**

When establishing a new connection in cases where free time is available between already running central link timing-events, best fit algorithm is used to find which free time space should be used. [Figure 28: Initiator - one or more connections as a central](#) on page 61 illustrates the case when all existing central connections have the same connection interval and the initiator timing-event starts around the same time as the 1st Central connection (C0) timing-event in the schedule. There is available time between C1 - C2 and between C2 - C3. Timing-event for new connection, Cn, is positioned in the available time between C2 - C3 because that is the best fit for Cn.



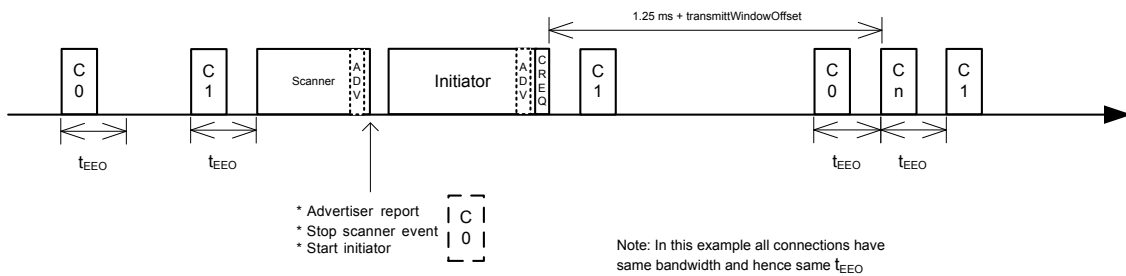
**Figure 28: Initiator - one or more connections as a central**

Figure 29: Initiator - free time not enough on page 62 illustrates the case when any free time between existing central link timing-events is not big enough to fit the new connection. The new central link timing-event is placed after all running central link timing-events in this case.



**Figure 29: Initiator - free time not enough**

When establishing connections to newly discovered devices, the scanner may be used for discovery followed by the initiator. In Figure 30: Initiator - fast connection on page 62, the initiator is started directly after discovering a new device to connect as fast as possible to that device. The initiator will always start asynchronously to the connected link events. The result is some link timing-events being dropped while the initiator timing-event runs. Link timing-events scheduled in the transmit window offset will not be dropped (C1). In this case time between C0 - C1 is available, and is allocated for the new connection (Cn).



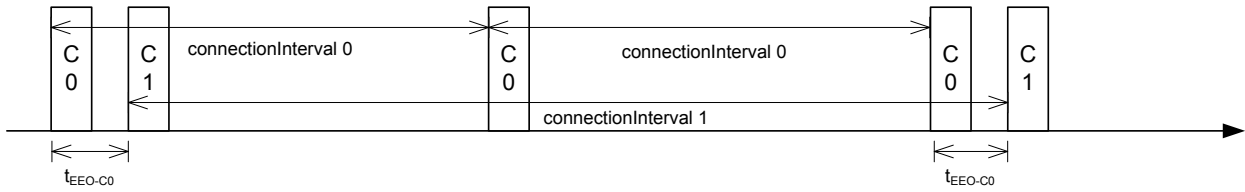
**Figure 30: Initiator - fast connection**

### 16.3 Connection timing as a central

Central link timing-events are added relative to already running central link timing-events.

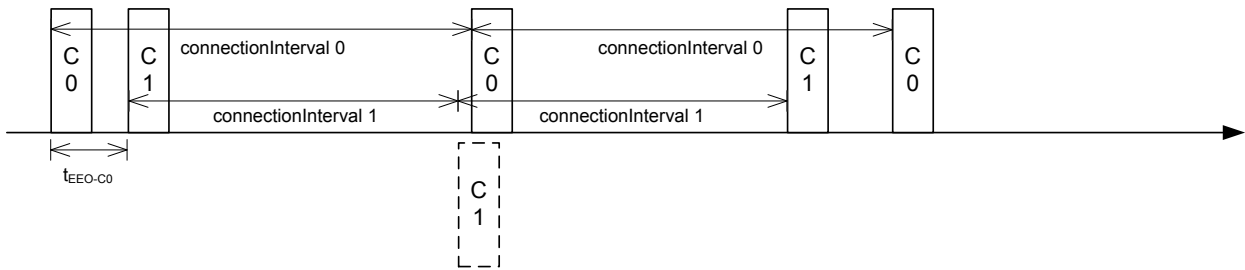
Central link timing-events are offset from each other by  $t_{EEO}$  depending on the bandwidth requirement of links. Refer to Initiator timing on page 60 for details about  $t_{EEO}$  and Table 25: BLE Radio Notification timing ranges on page 43 for its timing ranges.

Figure 31: Multilink scheduling - one or more connections as a central, factored intervals on page 63 shows a scenario where there are two links as a central established. C0 timing-events correspond to the first connection as a central made and C1 timing-events correspond to the second connection made. C1 timing-events are initially offset from C0 timing-events by  $t_{EEO-C0}$ . C1, in this example, have exactly double the connection interval of C0 (the connection intervals have a common factor which is "connectionInterval 0"), so the timing-events remain forever offset by  $t_{EEO-C0}$ .



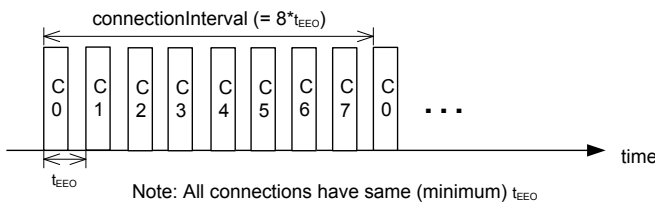
**Figure 31: Multilink scheduling - one or more connections as a central, factored intervals**

In [Figure 32: Multilink scheduling - one or more connections as a central, unfactored intervals](#) on page 63 the connection intervals do not have a common factor. This connection parameter configuration is possible, though this will result in dropped packets when events overlap. In this scenario, the second timing-event shown for C1 is dropped because it collides with the C0 timing-event.



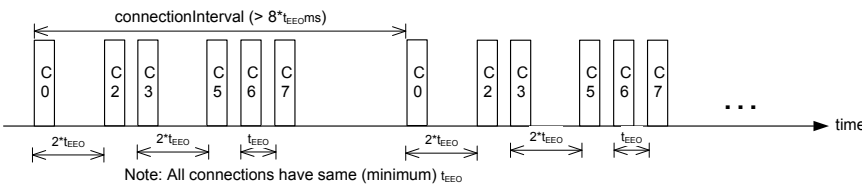
**Figure 32: Multilink scheduling - one or more connections as a central, unfactored intervals**

[Figure 33: Multilink scheduling with maximum connections as a central and minimum interval](#) on page 63 shows the maximum possible number of concurrent links as a Central (8), with maximum packet payload of 27 bytes, with minimum bandwidth (LOW bandwidth configuration), and with the minimum connection interval (15 ms), without having timing-event collisions and dropped packets. In this case, all available time is used for the links as a central.



**Figure 33: Multilink scheduling with maximum connections as a central and minimum interval**

[Figure 34: Multilink scheduling of connections as a central and interval > min](#) on page 63 shows a scenario similar to the one illustrated above except the connection interval is longer than the minimum, and Central 1 and 4 has been disconnected or does not have an timing-event in this time period. It shows the idle time during connection interval, and also shows that the timings of central link timing-events are not affected if other central links disconnects.

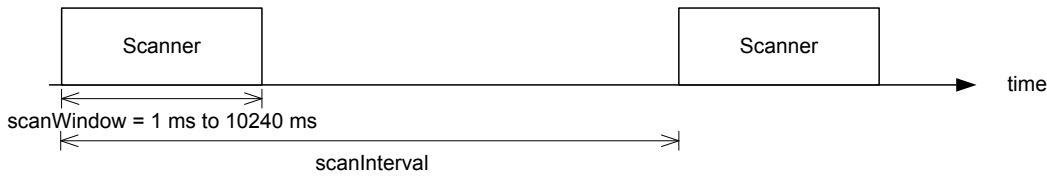


**Figure 34: Multilink scheduling of connections as a central and interval > min**

## 16.4 Scanner timing

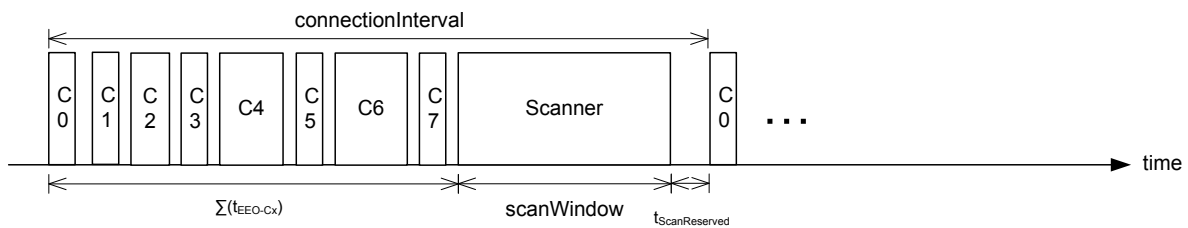
This section describes scanner timing with different connections.

Figure 35: Scanner timing - no active connections on page 64 shows that when scanning for advertisers with no active connections, the scan interval and window can be any value within the Bluetooth® Core Specification.



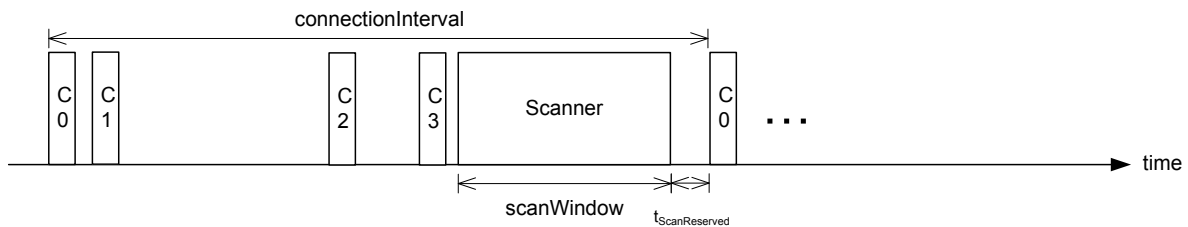
**Figure 35: Scanner timing - no active connections**

Scanner timing-event is always placed after the Central link timing-events. Figure 36: Scanner timing - one or more connection as a central on page 64 shows that when there is one or more active connections, the scanner or observer role timing-event will be placed after the link timing-events. With scanInterval equal to the connectionInterval and a scanWindow  $\leq$  (connectionInterval - ( $\sum t_{EEO-Cx}$  +  $t_{ScanReserved}$ )), scanning will proceed without packet loss.



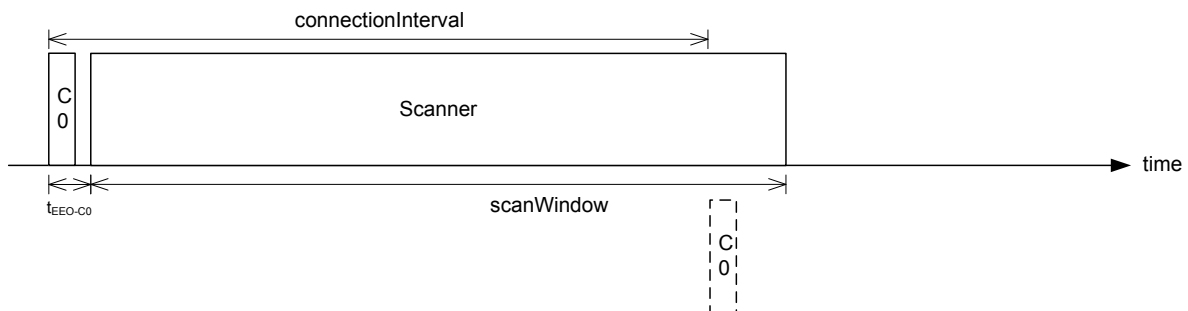
**Figure 36: Scanner timing - one or more connection as a central**

Figure 37: Scanner timing - always after connections on page 64 shows a scenario where free time is available between link timing-events, but still the scanner timing-event is placed after all connections.



**Figure 37: Scanner timing - always after connections**

Figure 38: Scanner timing - one connection, long window on page 64 shows a scanner with a long scanWindow which will cause some connection timing-events to be dropped.

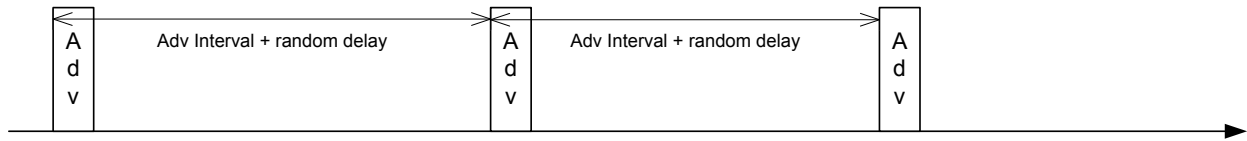


**Figure 38: Scanner timing - one connection, long window**



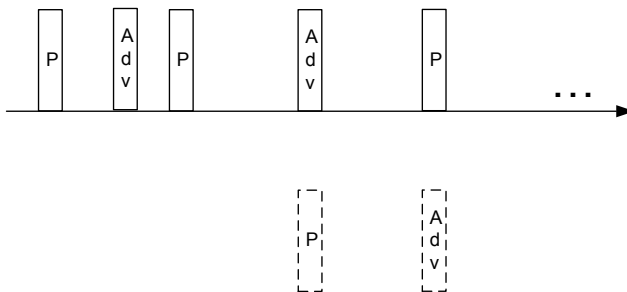
## 16.5 Advertiser (connectable and non-connectable) timing

Advertiser is started as early as possible, asynchronously to any other role timing-events. If no roles are running, advertiser timing-events are able to start and run without any collision.



**Figure 39: Advertiser**

When other role timing-events are running in addition, the advertiser role timing-event may collide with those. [Figure 40: Advertiser collide](#) on page 65 shows a scenario of advertiser colliding with peripheral (P).

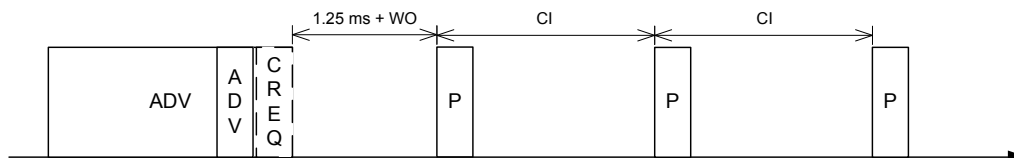


**Figure 40: Advertiser collide**

Directed advertiser is different compared to other advertiser types because it is not periodic. The scheduling of the single timing-event required by directed advertiser is done in the same way as other advertiser type timing-events. Directed advertiser timing-event is also started as early as possible, and its priority (refer to [Table 30: Scheduling priorities](#) on page 59) is raised if it is blocked by other role timing-events multiple times.

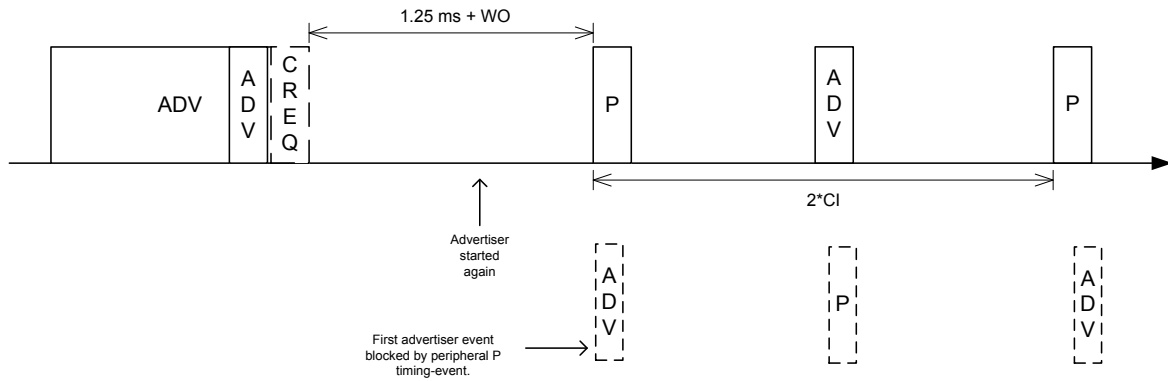
## 16.6 Peripheral connection setup and connection timing

Peripheral link timing-events are added as per the timing dictated by peer central.



**Figure 41: Peripheral connection setup and connection**

Peripheral link timing-events may collide with any other running role timing-events because the timing of the connection as a peripheral is dictated by the peer.



**Figure 42: Peripheral connection setup and connection with collision**

**Table 31: Peripheral role timing ranges**

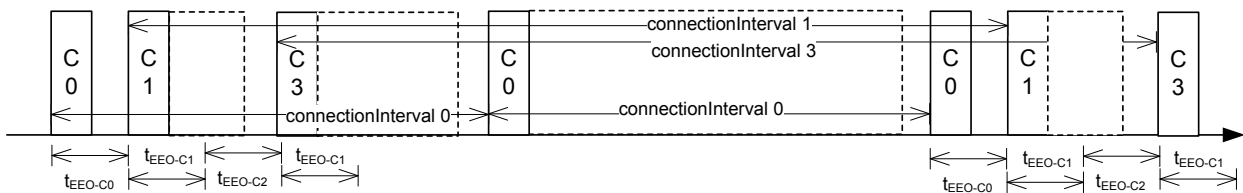
Value	Description	Value (µs)
$t_{SlaveNominalWindow}$	Listening window on slave to receive first packet in a connection event.	1000  (assuming 250 ppm sleep clock accuracy on both slave and master with 1 second connection interval)
$t_{SlaveEventNominal}$	Nominal event length for slave link.	$t_{prep(max)} + t_{SlaveNominalWindow} + t_{event(max)}$ (max for slave role)  Refer to <a href="#">Table 24: Notation and terminology for the Radio Notification used in this chapter on page 42</a> and <a href="#">Table 25: BLE Radio Notification timing ranges on page 43</a> .
$t_{SlaveEventMax}$	Maximum event length for slave link.	$t_{SlaveEventNominal} + 7\text{ ms}$  Where 7 ms is added for the maximum listening window for 500 ppm sleep clock accuracy on both master and slave with 4-second connection interval.
$t_{AdvEventMax}$	Maximum event length for advertiser (all types except directed advertiser) role.	$t_{prep(max)} + t_{event(max)}$ (max for adv role except directed adv)  Refer to <a href="#">Table 24: Notation and terminology for the Radio Notification used in this chapter on page 42</a> and <a href="#">Table 25: BLE Radio Notification timing ranges on page 43</a> .

## 16.7 Connection timing with Connection Event Length Extension

Central and peripheral links can extend the event if there is radio time available.

The connection event is the time within a timing-event reserved for sending or receiving packets. This is determined by the bandwidth configuration of the link and the size of the packets. The SoftDevice can be enabled to dynamically extend the connection event length to fit the maximum number of packets inside the connection event before the timing-event must be ended. The time extended will be in one packet pair at a time until the maximum extend time is reached. The connection event cannot be longer than the connection interval; the connection event will then end and the next connection event will begin. A connection event cannot be extended if it will collide with another timing-event. The extend request will ignore the priorities of the timing-events.

To get the maximum bandwidth on a single link, it is recommended to enable Connection Event Length Extension and increase the connection interval. This will allow the SoftDevice to send more packets within the event and limit the overhead of processing between connection events. To get the maximum bandwidth with multiple links it is recommended to enable Connection Event Length Extension and use the bandwidth levels to set the individual bandwidth requirements of the link. The SoftDevice can then dynamically increase the bandwidth beyond the bandwidth level if there is idle time between the connections. To get idle time between central links it is possible to give a central link bandwidth priority by giving it the lowest common factor interval. For more information, see [Suggested intervals and windows](#) on page 68.



**Figure 43: Example: Multilink scheduling utilizing idle time between timing-events**

Figure 43: Example: Multilink scheduling utilizing idle time between timing-events on page 67 shows a scheduling example where idle time in the radio scheduling can be used by the links to achieve higher bandwidth. Here C1 can utilize the free time left by a previously disconnected link C2, C3 has idle time as the last central link, and C0 is benefitting from having a connection interval set to half of that of C1 and C3.

## 16.8 Flash API timing

Flash timing-activity is a one-time activity with no periodicity, as opposed to BLE role timing-activities. Hence the flash timing-event is scheduled in any available time left between other timing-events.

To run efficiently with other timing-activities, the Flash API will run in lowest possible priority. Other timing-activities running in higher priority can collide with flash timing-events. Refer to [Table 30: Scheduling priorities](#) on page 59 for details on priority of timing-activities, which is used in case of collision. Flash timing-activity will use higher priority if it has been blocked many times by other timing-activities. Flash timing-activity may not get timing-event at all if other timing-events occupy most of the time and use priority higher than flash timing-activity. To avoid long waiting while using Flash API, flash timing-activity will fail in case it cannot get timing-event before a timeout.

## 16.9 Timeslot API timing

Radio Timeslot API timing-activity is scheduled independently of any other timing activity, hence it can collide with any other timing-activity in the SoftDevice.

Refer to [Table 30: Scheduling priorities](#) on page 59 for details on priority of timing-activities, which is used in case of collision. If the requested timing-event collides with already scheduled timing-events with equal or higher priority, the request will be denied (blocked). If a later arriving timing-activity of higher priority causes a

collision, the request will be canceled. However, a timing-event that has already started cannot be interrupted or canceled.

If the timeslot is requested as *earliest possible*, Timeslot timing-event is scheduled in any available free time. Hence there is less probability of collision with *earliest possible* request. Timeslot API timing-activity have two configurable priorities. To run efficiently with other timing-activities, the Timeslot API should run in lowest possible priority. It can be configured to use higher priority if it has been blocked many times by other timing-activities and is in a critical state.

## 16.10 Suggested intervals and windows

The time required to fit one timing-event of all active central links is equal to the sum of  $t_{EEO}$  of all active central links.

Therefore, eight link timing-events can complete in maximum  $\Sigma t_{EEO-Cx}$ , which is around 15 ms for 27 byte maximum packet payload and LOW bandwidth configuration. Refer to [Table 24: Notation and terminology for the Radio Notification used in this chapter](#) on page 42 and [Table 25: BLE Radio Notification timing ranges](#) on page 43 for timing ranges in central role.

Note that this does not leave sufficient time in the schedule for scanning or initiating new connections (when the number of connections already established is less than eight). Scanner, Observer, and Initiator events can therefore cause connection packets to be dropped.

It is recommended that all connections have intervals that have a common factor. This common factor should be greater or equal to  $\Sigma t_{EEO-Cx}$ . Note that this sum depends on number of connections and their respective bandwidth. In the case of eight connections with LOW bandwidth it is 15 ms, for three connections with MID bandwidth it is 11.25 ms (assuming maximum packet payload of 27 bytes). In case of using 15 ms as the common factor, all connections would have an interval of 15 ms or a multiple of 15 ms like 30 ms, 45 ms, etc.

If short connection intervals are not essential to the application and there is a need to have a scanner running at the same time as connections, then it is possible to avoid dropping packets on any connection as a central by having a connection interval larger than  $\Sigma t_{EEO-Cx}$  plus the scanWindow plus  $t_{ScanReserved}$ . Note that the initiator is scheduled asynchronously to any other role (and any other timing-activity), hence initiator timing-event might collide with other timing-events even if above recommendation is followed.

As an example, setting the connection interval to 43.75 ms will allow three connection events with MID bandwidth and a scan window of 31.0 ms, which is sufficient to ensure advertising packets from a 20 ms (nominal) advertiser hitting and being responded to within the window.

To summarize, a recommended configuration for operation without dropped packets for cases of only central roles running is:

- All central role intervals (i.e. connection interval, scanner/observer/initiator intervals) should have a common factor. This common factor should be  $\geq \Sigma t_{EEO-Cx} + \text{scanWindow} + t_{ScanReserved}$ .

Peripheral roles use the same time space as all other roles (including any other peripheral and central roles), hence a collision free schedule cannot be guaranteed if a peripheral role is running along with any other role. The probability of collision can be reduced (though not eliminated) if the central role link parameters are set as suggested in this section, and the following rules are applied for all roles:

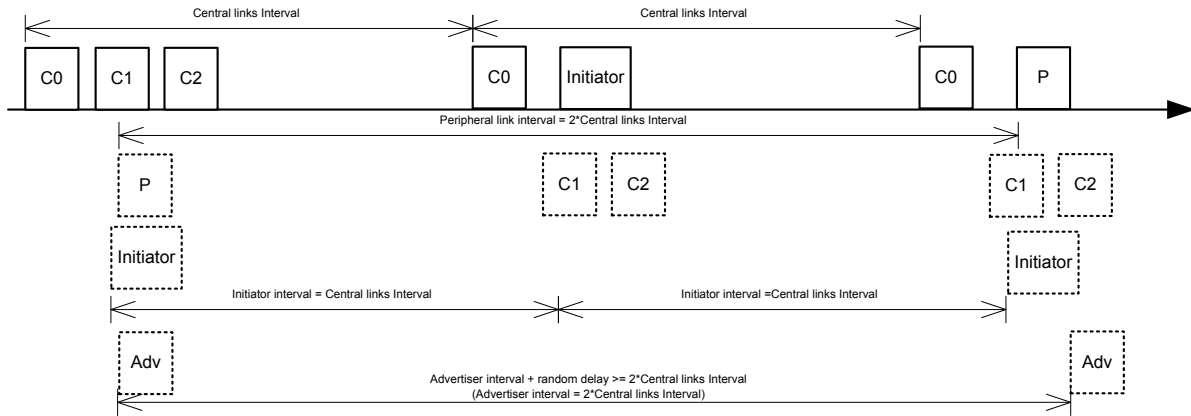
- Interval of all roles have a common factor which is  $\geq \Sigma t_{EEO-Cx} + (t_{ScanReserved} + \text{ScanWindow}) + t_{SlaveEventNominal} + t_{AdvEventMax}$

**Important:**  $t_{SlaveEventNominal}$  can be used in above equation in most cases, but should be replaced by  $t_{SlaveEventMax}$  for cases where links as a peripheral can have worst sleep clock accuracy and longer connection interval.

- Broadcaster and Advertiser roles also follow the constraint of interval which can be factored by the smallest connection interval.

**Important:** Directed advertiser is not considered here because that is not a periodic event.

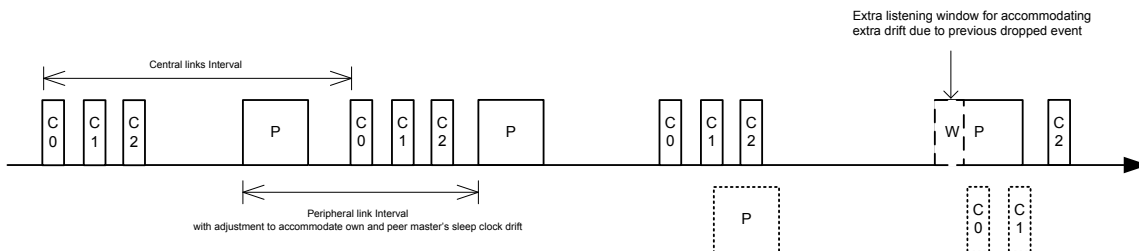
If only BLE role events are running and the above conditions are met, the worst case collision scenario will be broadcaster, connection as a peripheral, initiator and one or more connection as central colliding in time. The number of colliding connections as central depends on the maximum timing-event length of other asynchronous timing-activities. For example, it will be two connections as central if all connections have same bandwidth and both the initiator scan window and the  $t_{event}$  for the broadcaster are approximately equal to  $t_{EEO}$ . [Figure 44: Worst case collision of BLE roles](#) on page 69 shows this case of collision.



**Figure 44: Worst case collision of BLE roles**

These collisions will result in collision resolution via priority mechanism. The worst case collision will be reduced if any of the above roles are not running. For example, in the case of only connections as a central and slave connection is running, in the worst case each role will get a timing-event half the time because they both run with the same priority (Refer to [Table 30: Scheduling priorities](#) on page 59). [Figure 45: Three links running as a central and one peripheral](#) on page 69 shows this case of collision.

**Important:** These are worst case collision numbers, and an average case will most likely be better.



**Figure 45: Three links running as a central and one peripheral**

Timing-activities other than BLE role events, such as Flash access and Radio Timeslot API, also use the same time space as all other timing-activities. Hence they will also add up to the worst case collision scenario.

Packet drops might happen due to collision between different roles, as it is explained above. Application should tolerate dropped packets by setting the supervision time-out for connections long enough to avoid loss of connection when packets are dropped. For example, in case when only 3 central connections and one peripheral connection are running, in the worst case each role will get a timing-event half the time. To accommodate this packet drop, the application should set the supervision time-out to twice the size it would have set if only either Central or Peripheral role was running.

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## Chapter 17

# Interrupt model and processor availability

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This chapter documents the SoftDevice interrupt model, how interrupts are forwarded to the application, and describes how long the processor is used by the SoftDevice in different priority levels.

### 17.1 Exception model

As the SoftDevice, including the Master Boot Record (MBR), needs to handle some interrupts, all interrupts are routed through the MBR and SoftDevice. The ones that should be handled by the application are forwarded and the rest are handled within the SoftDevice itself. This section describes the interrupt forwarding mechanism.

For more information on the MBR, see [Master Boot Record and bootloader](#) on page 51.

#### 17.1.1 Interrupt forwarding to the application

The forwarding of interrupts to the application depends on the state of the SoftDevice.

At the lowest level, the MBR receives all interrupts and forwards them to the SoftDevice regardless of whether the SoftDevice is enabled or not. The use of a bootloader introduces some exceptions to this, see [Master Boot Record and bootloader](#) on page 51.

Some peripherals and their respective interrupt numbers are reserved for use by the SoftDevice (see [Hardware peripherals](#) on page 18). Any interrupt handler defined by the application for these interrupts will not be called as long as the SoftDevice is enabled. When the SoftDevice is disabled, these interrupts will be forwarded to the application.

The SVC interrupt is always intercepted by the SoftDevice regardless of whether it is enabled or disabled. The SoftDevice inspects the SVC number, and if it is equal or greater than 0x10, the interrupt is processed by the SoftDevice. SVC numbers below 0x10 are forwarded to the application's SVC interrupt handler. This allows the application to make use of a range of SVC numbers for its own purpose, for example, for an RTOS.

Interrupts not used by the SoftDevice are always forwarded to the application.

For the SoftDevice to locate the application interrupt vectors, the application must define its interrupt vector table at the bottom of the Application Flash Region illustrated in [Figure 24: Memory resource map](#) on page 55. When the base address of the application code is directly after the top address of the SoftDevice, the code can be developed as a standard ARM<sup>®</sup> Cortex<sup>®</sup>-M4 application project with the compiler creating the interrupt vector table.

#### 17.1.2 Interrupt latency due to System on Chip (SoC) framework

Latency, additional to ARM<sup>®</sup> Cortex<sup>®</sup>-M4 hardware architecture latency, is introduced by SoftDevice logic to manage interrupt events.

This latency occurs when an interrupt is forwarded to the application from the SoftDevice and is part of the minimum latency for each application interrupt. This is the latency added by the interrupt forwarding latency alone. The maximum application interrupt latency is dependent on SoftDevice activity, as described in section [Processor usage patterns and availability](#) on page 73.

**Table 32: Additional latency due to SoftDevice and MBR forwarding interrupts**

Interrupt	SoftDevice enabled	SoftDevice disabled
Open peripheral interrupt	< 2 $\mu$ s	< 1 $\mu$ s
Blocked or restricted peripheral interrupt (only forwarded when SoftDevice disabled)	N/A	< 2 $\mu$ s
Application SVC interrupt	< 2 $\mu$ s	< 2 $\mu$ s

## 17.2 Interrupt priority levels

This section gives an overview of interrupt levels used by the SoftDevice, and the interrupt levels that are available for the application.

To implement the SoftDevice API as SuperVisor Calls (SVCs, see [Application Programming Interface \(API\)](#) on page 11) and ensure that embedded protocol real-time requirements are met independently of the application processing, the SoftDevice implements an interrupt model where application interrupts and SoftDevice interrupts are interleaved. This model will result in application interrupts being postponed or preempted, leading to longer perceived application interrupt latency and interrupt execution times.

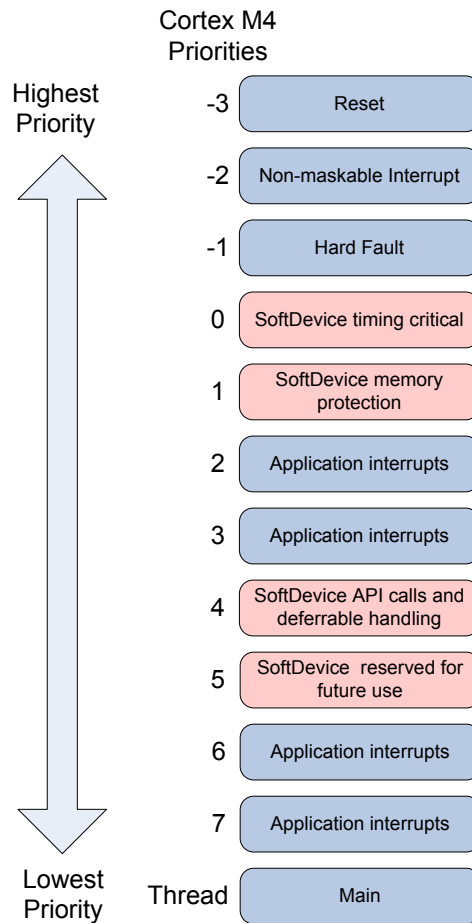
The application must take care to select the correct interrupt priorities for application events according to the guidelines that follow. The NVIC API to the SoC Library supports safe configuration of interrupt priorities from the application.

The ARM<sup>®</sup> Cortex<sup>®</sup>-M4 processor has eight configurable interrupt priorities ranging from 0 to 7 (with 0 being highest priority). On reset, all interrupts are configured with the highest priority (0).

The SoftDevice reserves and uses the following priority levels, which must remain unused by the application programmer:

- Level 0 is used for the SoftDevice's timing critical processing.
- Level 1 is used for handling the memory isolation and run time protection, see [Memory isolation and runtime protection](#) on page 13.
- Level 4 is used by higher level deferrable tasks and the API functions executed as SVC interrupts.
- Level 5 is reserved for future use.

The application can use the remaining interrupt priority levels, in addition to the main, or thread, context.



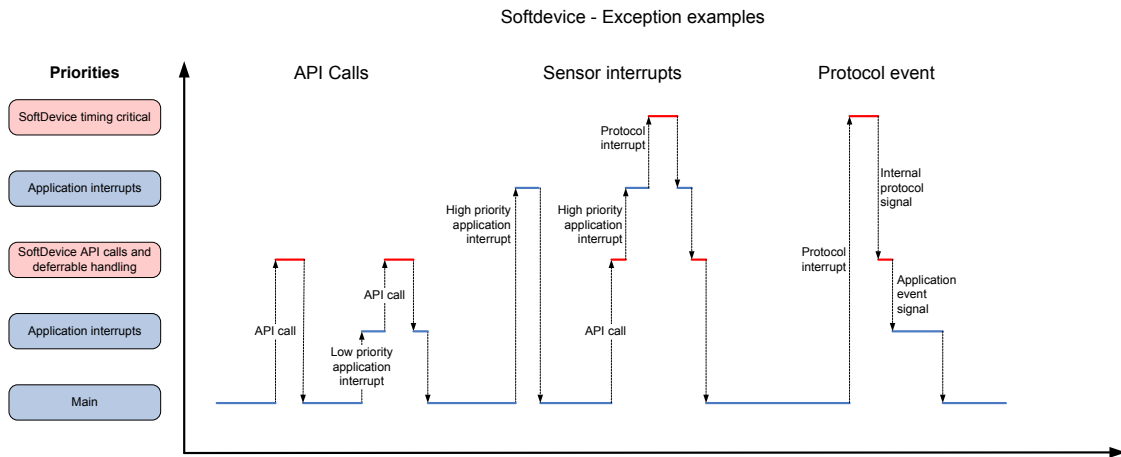
**Figure 46: Exception model**

As seen from [Figure 46: Exception model](#) on page 72, the application has available priority level 2 and 3, located between the higher and lower priority levels reserved by the SoftDevice. This enables a low-latency application interrupt to support fast sensor interfaces. An application interrupt at priority level 2 or 3 will only experience latency from SoftDevice interrupts at priority levels 0 and 1, while application interrupts at priority levels 6 or 7 can experience latency from all SoftDevice priority levels.

**Important:** The priorities of the interrupts reserved by the SoftDevice cannot be changed. This includes the SVC interrupt. Handlers running at a priority level higher than 4 (lower numerical priority value) have neither access to SoftDevice functions nor to application specific SVCs or RTOS functions running at lower priority levels (higher numerical priority values).

[Figure 47: SoftDevice exception examples \(some priority levels left out for clarity\)](#) on page 73 shows an example of how interrupts with different priorities may run and preempt each other. Note that some priority levels are left out for clarity.





**Figure 47: SoftDevice exception examples (some priority levels left out for clarity)**

### 17.3 Processor usage patterns and availability

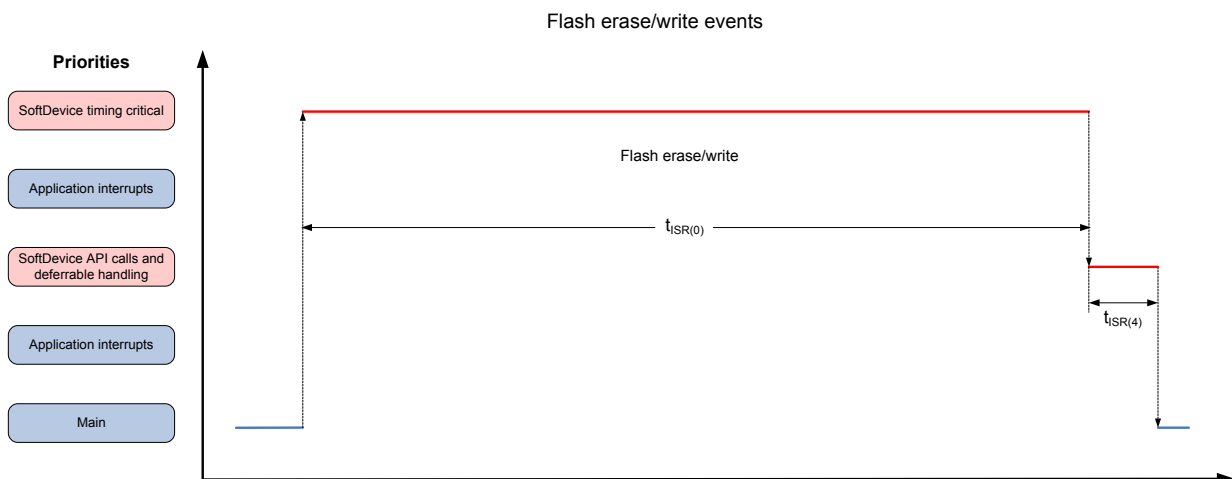
This section gives an overview of the processor usage patterns for features of the SoftDevice, and the processor availability to the application in stated scenarios.

The SoftDevice's processor use will also affect the maximum interrupt latency for application interrupts of lower priority (higher numerical value for the interrupt priority). The maximum interrupt processing time for the different priority levels in this chapter can be used to calculate the worst case interrupt latency the application will have to handle when the SoftDevice is used in various scenarios.

In the scenarios to follow,  $t_{ISR(x)}$  denotes interrupt processing time at priority level  $x$ , and  $t_{nISR(x)}$  denotes time between interrupts at priority level  $x$ .

#### 17.3.1 Flash API processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice when the Flash API is being used.



**Figure 48: Flash API activity (some priority levels left out for clarity)**

When using the Flash API, the pattern of SoftDevice CPU activity at interrupt priority level 0 is as follows:

- First, there is an interrupt at priority level 0 that sets up and performs the flash activity. The CPU is halted for most of the time in this interrupt.

- After the first interrupt is finished, there is another interrupt at priority level 4 that does some cleanup after the flash operation.

SoftDevice processing activity in the different priority levels during flash erase and write is outlined in the table below.

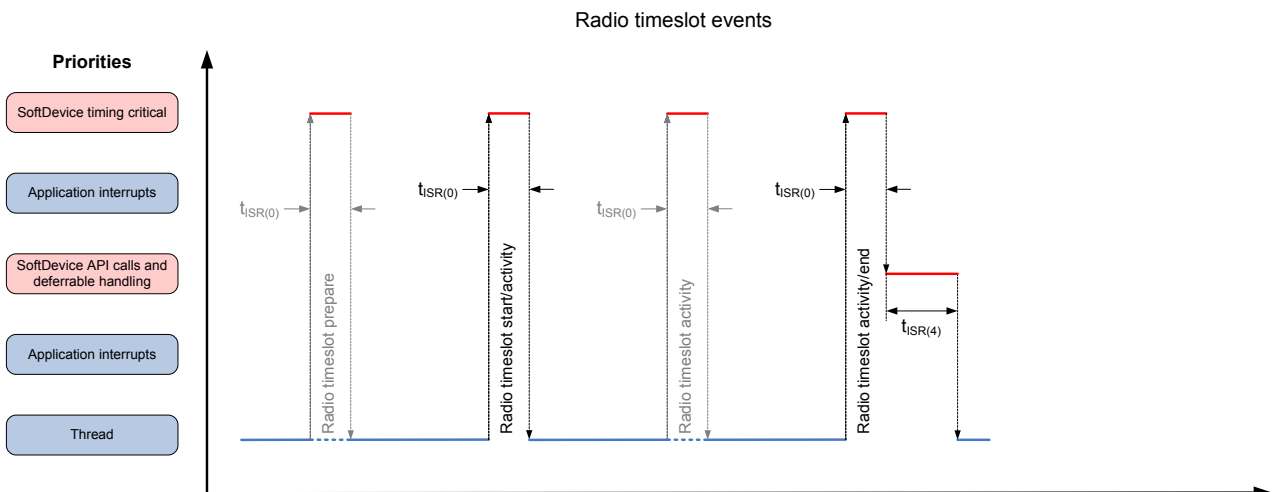
**Table 33: Processor usage for the Flash API**

Parameter	Description	Min	Typical	Max
$t_{ISR(0),FlashErase}$	Interrupt processing when erasing a flash page. Note that the CPU is halted most of the length of this interrupt.			90 ms
$t_{ISR(0),FlashWrite}$	Interrupt processing when writing one or more words to flash. Note that the CPU is halted most of the length of this interrupt. The Max time provided is for writing one word. When writing more than one word, please see the Product Specification to find out how long time is needed for per word to write, and add to the Max time provided in this table.			500 $\mu$ s
$t_{ISR(4)}$	Priority level 4 interrupt at the end of flash write or erase.		10 $\mu$ s	

### 17.3.2 Radio Timeslot API processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice when the Radio Timeslot API is being used.

See [Radio Timeslot API](#) on page 27 for more information on the Radio Timeslot API.



**Figure 49: Radio Timeslot API activity (some priority levels left out for clarity)**

When using the Radio Timeslot API, the pattern of SoftDevice CPU activity at interrupt priority level 0 is as follows:

- If the timeslot was requested with `NRF_RADIO_HFCLK_CFG_XTAL_GUARANTEED`, there is first an interrupt that handles the startup of the high frequency crystal.

- Then there are one or more radio timeslot activities. How many and how long these are, is application dependent.
- When the last of the radio timeslot activities are finished, there is another interrupt at priority level 4 that does some cleanup after the Radio Timeslot operation.

SoftDevice processing activity in the different priority levels during use of Radio Timeslot API is outlined in the table below.

**Table 34: Processor usage for the Radio Timeslot API**

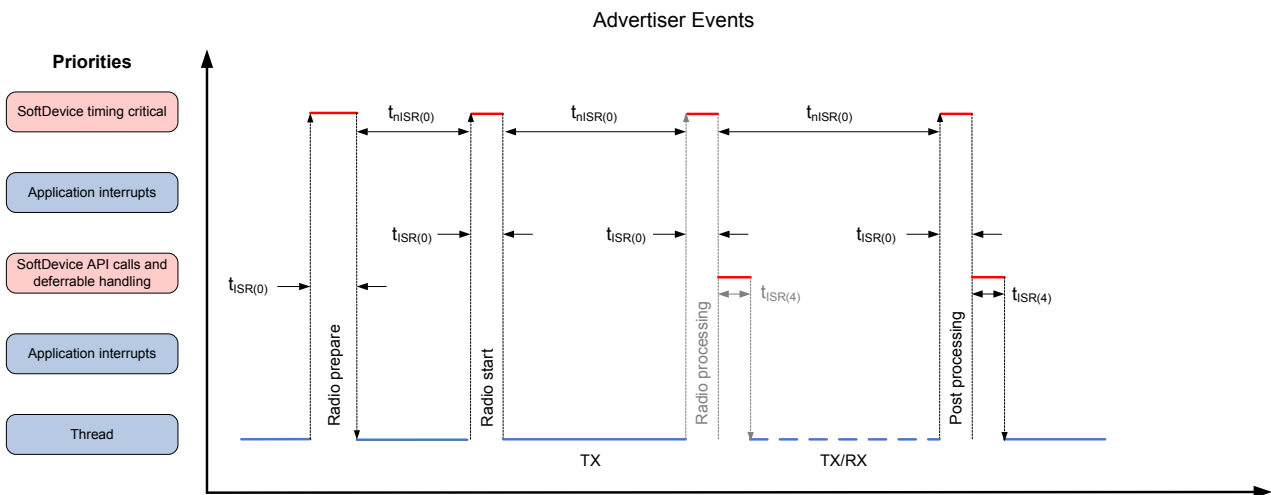
Parameter	Description	Min	Typical	Max
$t_{ISR(0),RadioTimeslotPrepare}$	Interrupt processing when starting up the high frequency crystal.			9 $\mu$ s
$t_{ISR(0),RadioTimeslotActivity}$	The application's processing in the timeslot. The length of this is application dependent.			
$t_{ISR(4)}$	Priority level 4 interrupt at the end of the timeslot.		7 $\mu$ s	

### 17.3.3 BLE processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice when roles of the BLE protocol are running.

#### 17.3.3.1 BLE advertiser (broadcaster) processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice when the advertiser (broadcaster) role is running.



**Figure 50: Advertising events (some priority levels left out for clarity)**

When advertising, the pattern of SoftDevice processing activity for each advertising interval, at interrupt priority level 0 is as follows:

- First, there is an interrupt (Radio prepare) that sets up and prepares the software and hardware for this advertising event.
- Then there is a short interrupt when the radio starts sending the first advertising packet.
- Depending on the type of advertising, there may be one or more instances of Radio processing (including processing in priority level 4) and further receptions/transmissions.
- Finally, advertising ends with Post processing at interrupt priority level 0 and some interrupt priority level 4 activity.

SoftDevice processing activity in the different priority levels when advertising is outlined in [Table 35: Processor usage when advertising](#) on page 76. The typical case is seen when advertising without using a whitelist and without receiving scan or connect requests. The max case can be seen when advertising with a full whitelist, receiving scan and connect requests while having a maximum number of connections and utilizing the Radio Timeslot API and Flash memory API at the same time.

**Table 35: Processor usage when advertising**

Parameter	Description	Min	Typical	Max
$t_{ISR(0),RadioPrepare}$	Processing preparing the radio for advertising.		24 $\mu$ s	50 $\mu$ s
$t_{ISR(0),RadioStart}$	Processing when starting the advertising.		13 $\mu$ s	20 $\mu$ s
$t_{ISR(0),RadioProcessing}$	Processing after sending/receiving a packet.		20 $\mu$ s	40 $\mu$ s
$t_{ISR(0),PostProcessing}$	Processing at the end of an advertising event.		75 $\mu$ s	190 $\mu$ s
$t_{nISR(0)}$	Distance between interrupts during advertising.	40 $\mu$ s	>170 $\mu$ s	
$t_{ISR(4)}$	Priority level 4 interrupt at the end of an advertising event.		75 $\mu$ s	

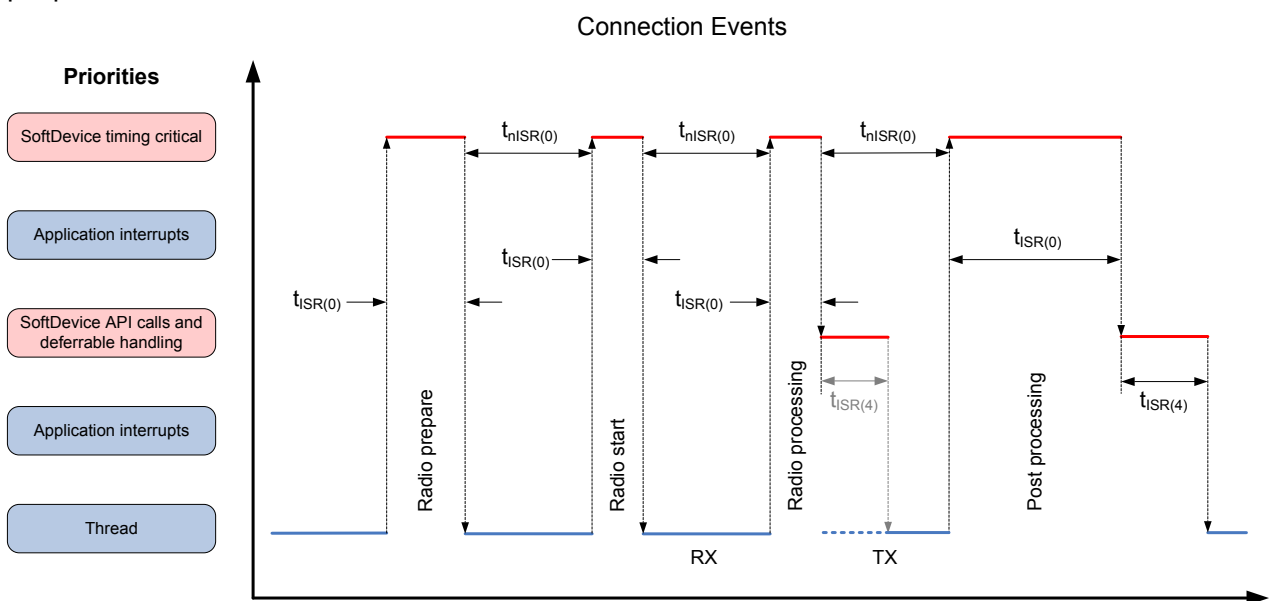
From the table, we can calculate a typical processing time for one advertisement event sending three advertisement packets to be

$$t_{ISR(0),RadioPrepare} + t_{ISR(0),RadioStart} + 2 * t_{ISR(0),RadioProcessing} + t_{ISR(0),PostProcessing} + t_{ISR(4)} = 227 \mu s$$

which means that typically more than 99% of the processor time is available to the application when advertising with a 100 ms interval.

**17.3.3.2 BLE peripheral connection processor usage patterns**

This section describes the processor availability and interrupt processing time for the SoftDevice in a peripheral connection event.



**Figure 51: Peripheral connection events (some priority levels left out for clarity)**

In a peripheral connection event, the pattern of SoftDevice processing activity at interrupt priority level 0 is typically as follows:

- First, there is an interrupt (Radio prepare) that sets up and prepares the software and hardware for the connection event.
- Then there is a short interrupt when the radio starts listening for the first packet.
- When the reception is finished, there is Radio processing that processes the received packet and switches the radio to transmission.
- When the transmission is finished, there is either a Radio processing including a switch back to reception and possibly a new transmission after that, or the event ends with post processing.
- After the radio and post processings in priority level 0, the SoftDevice processes any received data packets, executes any GATT, ATT or SMP operations and generates events to the application as required in priority level 4. The interrupt at this priority level is therefore highly variable based on the stack operations executed.

SoftDevice processing activity in the different priority levels during peripheral connection events is outlined in [Table 36: Processor usage when connected](#) on page 77. The typical case is seen when sending GATT write commands writing 20 bytes. The max case can be seen when sending and receiving maximum length packets and at the same time initiating encryption, while having a maximum number of connections and utilizing the Radio Timeslot API and Flash memory API at the same time.

**Table 36: Processor usage when connected**

Parameter	Description	Min	Typical	Max
$t_{ISR(0),RadioPrepare}$	Processing preparing the radio for a connection event.		35 $\mu$ s	50 $\mu$ s
$t_{ISR(0),RadioStart}$	Processing when starting the connection event.		15 $\mu$ s	20 $\mu$ s
$t_{ISR(0),RadioProcessing}$	Processing after sending or receiving a packet.		30 $\mu$ s	40 $\mu$ s
$t_{ISR(0),PostProcessing}$	Processing at the end of a connection event.		90 $\mu$ s	231 $\mu$ s
$t_{nISR(0)}$	Distance between interrupts during a connection event.	30 $\mu$ s	> 190 $\mu$ s	
$t_{ISR(4)}$	Priority level 4 interrupt after a packet is sent or received.		40 $\mu$ s	

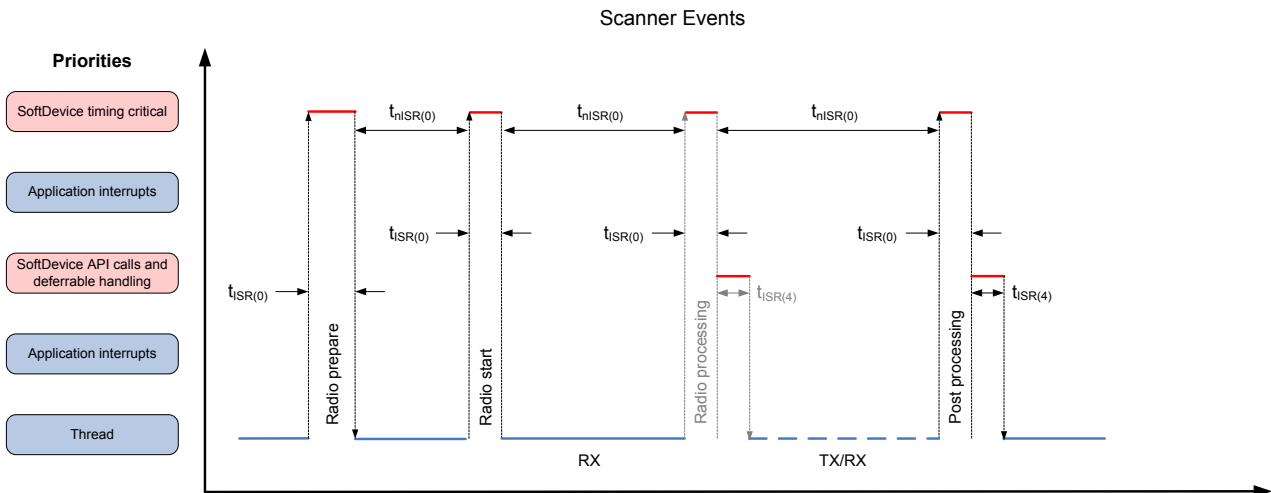
From the table, we can calculate a typical processing time for a peripheral connection event where one packet is sent and received to be

$$t_{ISR(0),RadioPrepare} + t_{ISR(0),RadioStart} + t_{ISR(0),RadioProcessing} + t_{ISR(0),PostProcessing} + 2 * t_{ISR(4)} = 250 \mu s$$

which means that typically more than 99% of the processor time is available to the application when one peripheral link is established and one packet is sent in each direction with a 100 ms connection interval.

### 17.3.3.3 BLE scanner and initiator processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice when the scanner or initiator role is running.



**Figure 52: Scanning or initiating (some priority levels left out for clarity)**

When scanning or initiating, the pattern of SoftDevice processing activity at interrupt priority level 0 is as follows:

- First, there is an interrupt (Radio prepare) that sets up and prepares the software and hardware for this scanner or initiator event.
- Then there is a short interrupt when the radio starts listening for advertisement packets.
- During scanning, there will be zero or more instances of Radio processing, depending upon whether the active role is a scanner or an initiator, whether scanning is passive or active, whether advertising packets are received or not and upon the type of the received advertising packets. Such Radio processing may be followed by the SoftDevice processing at interrupt priority level 4.
- When the event ends (either by timeout, or if the initiator receives a connectable advertisement packet it accepts), the SoftDevice does some Post processing, which may be followed by processing at interrupt priority level 4.

SoftDevice processing activity in the different priority levels when scanning or initiating is outlined in [Table 37: Processor usage for scanning or initiating](#) on page 78. The typical case is seen when scanning or initiating without using a whitelist and without sending scan or connect requests. The max case can be seen when scanning or initiating with a full whitelist, sending scan or connect requests while having a maximum number of connections and utilizing the Radio Timeslot API and Flash memory API at the same time.

**Table 37: Processor usage for scanning or initiating**

Parameter	Description	Min	Typical	Max
$t_{ISR(0),RadioPrepare}$	Processing preparing the radio for scanning or initiating.		18 $\mu$ s	48 $\mu$ s
$t_{ISR(0),RadioStart}$	Processing when starting the scan or initiation.		19 $\mu$ s	25 $\mu$ s
$t_{ISR(0),RadioProcessing}$	Processing after sending/receiving packet.		38 $\mu$ s	60 $\mu$ s
$t_{ISR(0),PostProcessing}$	Processing at the end of a scanner or initiator event.		68 $\mu$ s	190 $\mu$ s
$t_{nISR(0)}$	Distance between interrupts during scanning.	30 $\mu$ s	>1.5 ms	
$t_{ISR(4)}$	Priority level 4 interrupt at the end of a scanner or initiator event.		70 $\mu$ s	

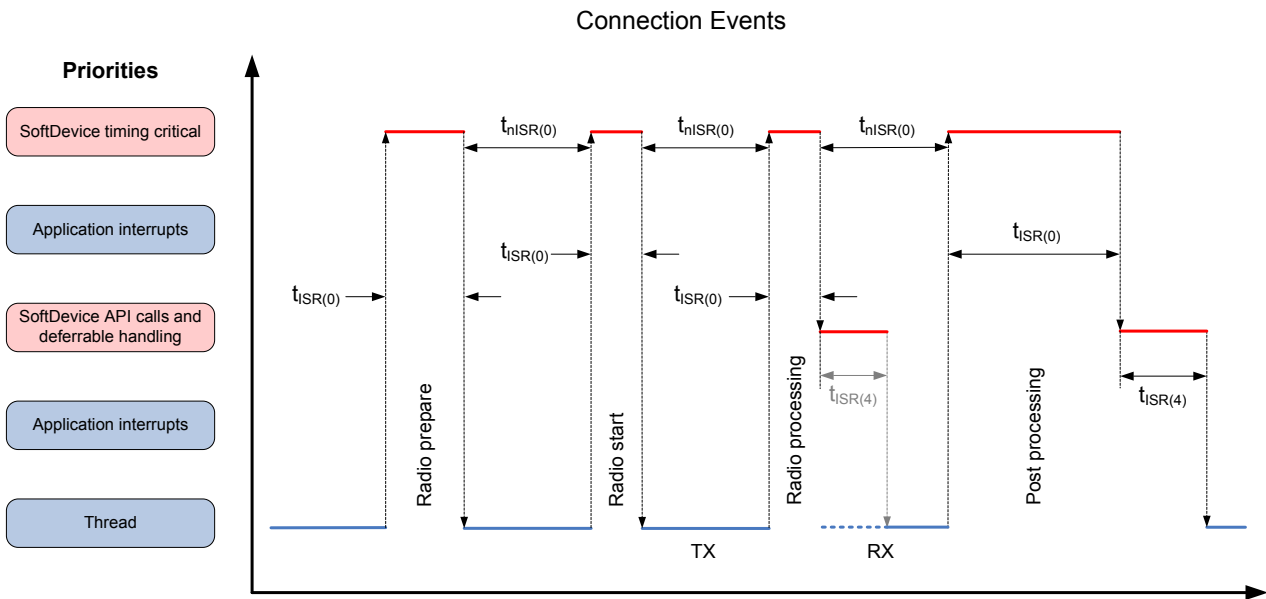
From the table, we can calculate a typical processing time for one scan event receiving one advertisement packet to be

$$t_{ISR(0),RadioPrepare} + t_{ISR(0),RadioStart} + t_{ISR(0),RadioProcessing} + t_{ISR(0),PostProcessing} + t_{ISR(4)} = 213 \mu s$$

which means that typically more than 99% of the processor time is available to the application when scanning with a 100 ms interval under these conditions.

### 17.3.3.4 BLE central connection processor usage patterns

This section describes the processor availability and interrupt processing time for the SoftDevice in a central connection event.



**Figure 53: Central connection events (some priority levels left out for clarity)**

In a central connection event, the pattern of SoftDevice processing activity at interrupt priority level 0 is typically as follows:

- First, there is an interrupt (Radio prepare) that sets up and prepares the software and hardware.
- Then there is a short interrupt when the radio starts transmitting the first packet in the connection event.
- When the transmission is finished, there is Radio processing that switches the radio to reception.
- When the reception is finished, there is a Radio processing that processes the received packet, and either including a switch back to transmission and possibly a new reception after that, or the event ends with post processing.
- After the radio and post processings in priority level 0, the SoftDevice processes any received data packets, executes any GATT, ATT or SMP operations and generates events to the application as required in priority level 4. The interrupt at this priority level is therefore highly variable based on the stack operations executed.

SoftDevice processing activity in the different priority levels during central connection events is outlined in [Table 38: Processor usage latency when connected](#) on page 80. The typical case is seen when receiving GATT write commands writing 20 bytes. The max case can be seen when sending and receiving maximum length packets and at the same time initiating encryption, while having a maximum number of connections and utilizing the Radio Timeslot API and Flash memory API at the same time.

**Table 38: Processor usage latency when connected**

Parameter	Description	Min	Typical	Max
$t_{ISR(0),RadioPrepare}$	Processing preparing the radio for a connection event.		29 $\mu$ s	47 $\mu$ s
$t_{ISR(0),RadioStart}$	Processing when starting the connection event.		19 $\mu$ s	25 $\mu$ s
$t_{ISR(0),RadioProcessing}$	Processing after sending or receiving a packet.		30 $\mu$ s	60 $\mu$ s
$t_{ISR(0),PostProcessing}$	Processing at the end of a connection event.		90 $\mu$ s	230 $\mu$ s
$t_{nISR(0)}$	Distance between connection event interrupts.	30 $\mu$ s	> 195 $\mu$ s	
$t_{ISR(4)}$	Priority level 4 interrupt after a packet is sent or received.		40 $\mu$ s	

From the table, we can calculate a typical processing time for a central connection event where one packet is sent and received to be

$$t_{ISR(0),RadioPrepare} + t_{ISR(0),RadioStart} + t_{ISR(0),RadioProcessing} + t_{ISR(0),PostProcessing} + 2 * t_{ISR(4)} = 248 \mu s$$

which means that typically more than 99% of the processor time is available to the application when one peripheral link is established and one packet is sent in each direction with a 100 ms connection interval.

### 17.3.4 Interrupt latency when using multiple modules and roles

Concurrent use of the Flash API, Radio Timeslot API and/or one or more BLE roles can affect interrupt latency.

The same interrupt priority levels are used by all Flash API, Radio Timeslot API and BLE roles. When using more than one of these concurrently, their respective events can be scheduled back-to-back (see [Scheduling](#) on page 26 for more on scheduling). In those cases, the last interrupt in the activity by one module/role can be directly followed by the first interrupt of the next activity. Therefore, to find the real worst-case interrupt latency in these cases the application developer must add the latency of the first and last interrupt for all combination of roles that are used.

Example: If the application uses the Radio Timeslot API while having a BLE advertiser running, the worst case interrupt latency or interruption for an application interrupt is the largest of

- The worst case interrupt latency of the Radio Timeslot API
- The worst case interrupt latency of the BLE advertiser role
- The sum of the max time of the first interrupt of the Radio Timeslot API and the last interrupt of the BLE advertiser role
- The sum of the max time of the first interrupt of the BLE advertiser role and the last interrupt of the Radio Timeslot API

for the SoftDevice interrupts with higher priority level (lower numerical value) as the application interrupt.



# Chapter 18

## BLE data throughput

This chapter gives an indication of achievable BLE connection throughput for GATT procedures used to send and receive data in stated SoftDevice configurations.

Maximum throughput will only be possible when the application reads data packets as they are received, and provides new data as packets are transmitted, without delay. The SoftDevice may transfer more packets than reserved by the bandwidth configuration when data transfer is simplex (read or write only), because extra time is available in the event to transfer data, or the event can be extended beyond its reserved time. See [Connection timing with Connection Event Length Extension](#) on page 67.

All data throughput values apply to packet transfers over an encrypted connection using maximum payload sizes. Maximum LL payload size is 27 bytes, unless noted otherwise.

**Table 39: Maximum data throughput with a single peripheral or central connection and a connection interval of 7.5 ms**

Protocol	ATT MTU size	BW Config	Method	Maximum data throughput
GATT Client	23	HIGH	Receive Notification	149.3 kbps
			Send Write command	149.3 kbps
			Send Write request	10.6 kbps
			Simultaneous receive Notification and send Write command	127.9 kbps (each direction)
GATT Server	23	HIGH	Send Notification	149.3 kbps
			Receive Write command	149.3 kbps
			Receive Write request	10.6 kbps
			Simultaneous send Notification and receive Write command	127.9 kbps (each direction)
GATT Server	158	HIGH	Send Notification	247.8 kbps
			Receive Write command	247.0 kbps
			Receive Write request	82.6 kbps
			Simultaneous send Notification and receive Write command	165.4 kbps (each direction)
GATT Client	23	MID	Receive Notification	63.9 kbps
			Send Write command	63.9 kbps
			Send Write request	10.6 kbps
				63.9 kbps (each direction)

Protocol	ATT MTU size	BW Config	Method	Maximum data throughput
			Simultaneous receive Notification and send Write command	
GATT Server	23	MID	Send Notification Receive Write command Receive Write request Simultaneous send Notification and receive Write command	63.9 kbps 63.9 kbps 10.6 kbps 63.9 kbps (each direction)
GATT Client	23	LOW	Receive Notification Send Write command Send Write request Simultaneous receive Notification and send Write command	21.3 kbps 21.3 kbps 10.6 kbps 21.3 kbps (each direction)
GATT Server	23	LOW	Send Notification Receive Write command Receive Write request Simultaneous send Notification and receive Write command	21.3 kbps 21.3 kbps 10.6 kbps 21.3 kbps (each direction)

**Table 40: Maximum data throughput with a single peripheral or central connection and DLE and Connection Event Length Extension enabled**

Protocol	ATT MTU size	LL payload size	Connection interval	Method	Maximum data throughput
GATT Server	247	251 <sup>10</sup>	50 ms	Send Notification Receive Write command Simultaneous send Notification and receive Write command	701.8 kbps 701.5 kbps 390.0 kbps (each direction)
GATT Server	247	251	400 ms	Send Notification Receive Write command	765.8 kbps 752.2 kbps 421.7 kbps (each direction)

<sup>10</sup> Under the assumption that the peer device accepts the increased ATT and LL payload sizes.

Protocol	ATT MTU size	LL payload size	Connection interval	Method	Maximum data throughput
				Simultaneous send Notification and receive Write command	
Raw Link Layer data	N/A	251	400 ms	N/A	803 kbps

The following table [Table 41: Maximum data throughput for each connection, up to 8 connections with 23 byte ATT MTU and no DLE](#) on page 83 shows maximum data throughput at a connection interval of 15 ms that allows up to 8 LOW bandwidth concurrent connections per interval.

Only throughput for LOW bandwidth configuration is indicated. For higher bandwidth configurations, a longer connection interval would need to be used for each connection to prevent connection events from overlapping. See [Scheduling](#) on page 59 for more information on how connections can be configured.

Throughput may get reduced if a peripheral link is running because peripheral links are not synchronized with central links. If a peripheral link is running, throughput may decrease to half for up to two central links and the peripheral link.

**Table 41: Maximum data throughput for each connection, up to 8 connections with 23 byte ATT MTU and no DLE**

Protocol	BW Config	Method	Maximum data throughput
GATT - Client	LOW	Receive Notification	9.1 kbps
		Send Write command	9.0 kbps
		Send Write request	4.5 kbps
		Simultaneous receive Notification and send Write command	9.1 kbps (each direction)
GATT - Server	LOW	Send Notification	9.1 kbps
		Receive Write command	9.0 kbps
		Receive Write request	4.5 kbps
		Simultaneous send Notification and receive Write command	9.1 kbps (each direction)

**Important:** 1 kbps = 1000 bits per second

# Chapter 19

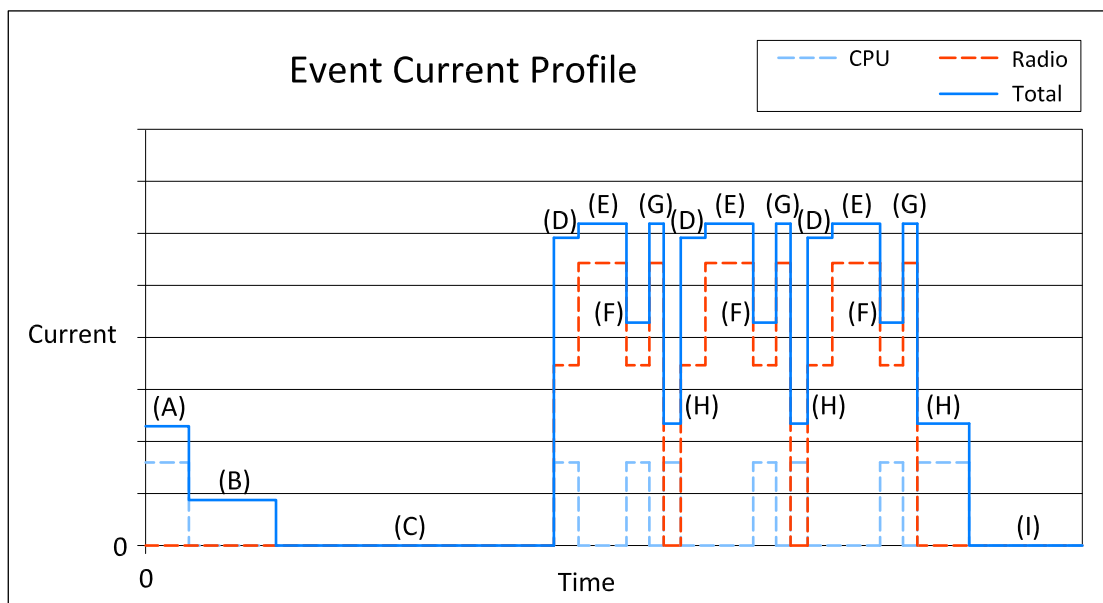
## BLE power profiles

The power profile diagrams in this chapter give an overview of the stages within a *Bluetooth*<sup>®</sup> low energy Radio Event implemented by the SoftDevice. The profiles illustrate battery current versus time and briefly describe the stages that could be observed.

These profiles are based on typical events with empty packets. In all cases, “Standby” is a state of the SoftDevice where all peripherals are IDLE.

### 19.1 Advertising event

This section gives an overview of the power profile of the advertising event implemented in the SoftDevice.



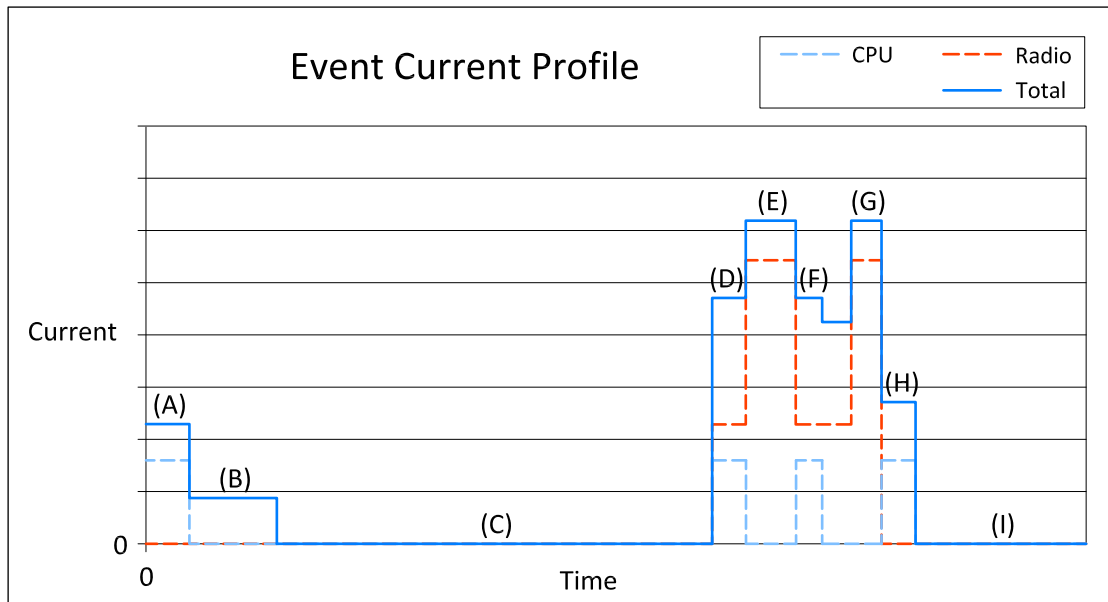
**Figure 54: Advertising event**

**Table 42: Advertising event**

Stage	Description
(A)	Pre-processing (CPU)
(B)	Standby + HFXO ramp
(C)	Standby
(D)	Radio startup
(E)	Radio TX
(F)	Radio switch
(G)	Radio RX
(H)	Post-processing (CPU)
(I)	Standby

## 19.2 Peripheral connection event

This section gives an overview of the power profile of the peripheral connection event implemented in the SoftDevice.



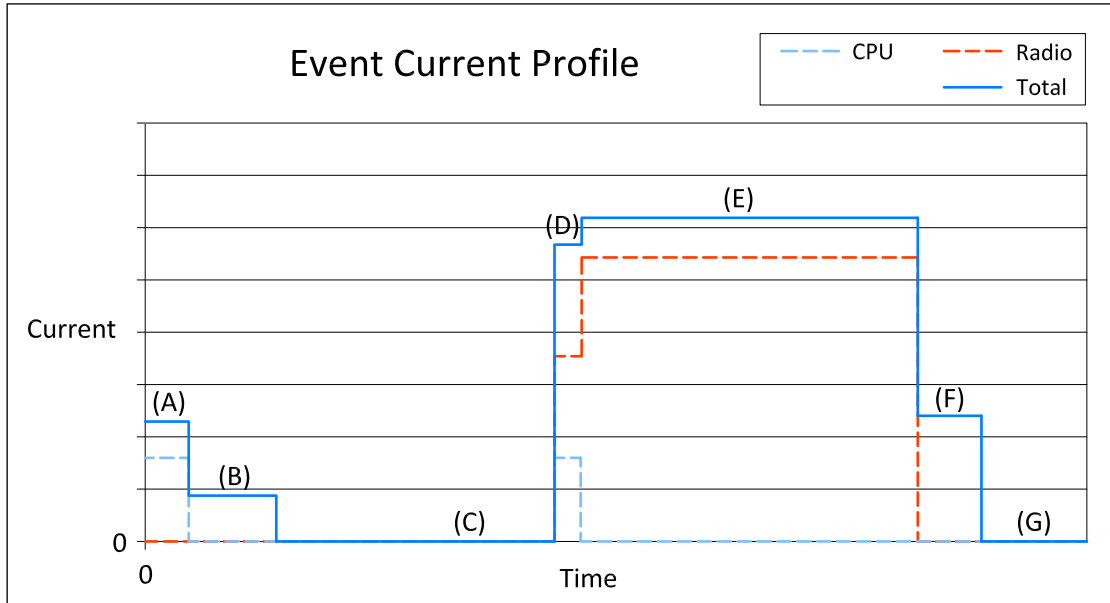
**Figure 55: Peripheral connection event**

**Table 43: Peripheral connection event**

Stage	Description
(A)	Pre-processing (CPU)
(B)	Standby + HFXO ramp
(C)	Standby
(D)	Radio startup
(E)	Radio RX
(F)	Radio switch
(G)	Radio TX
(H)	Post-processing (CPU)
(I)	Standby

## 19.3 Scanning event

This section gives an overview of the power profile of the scanning event implemented in the SoftDevice.



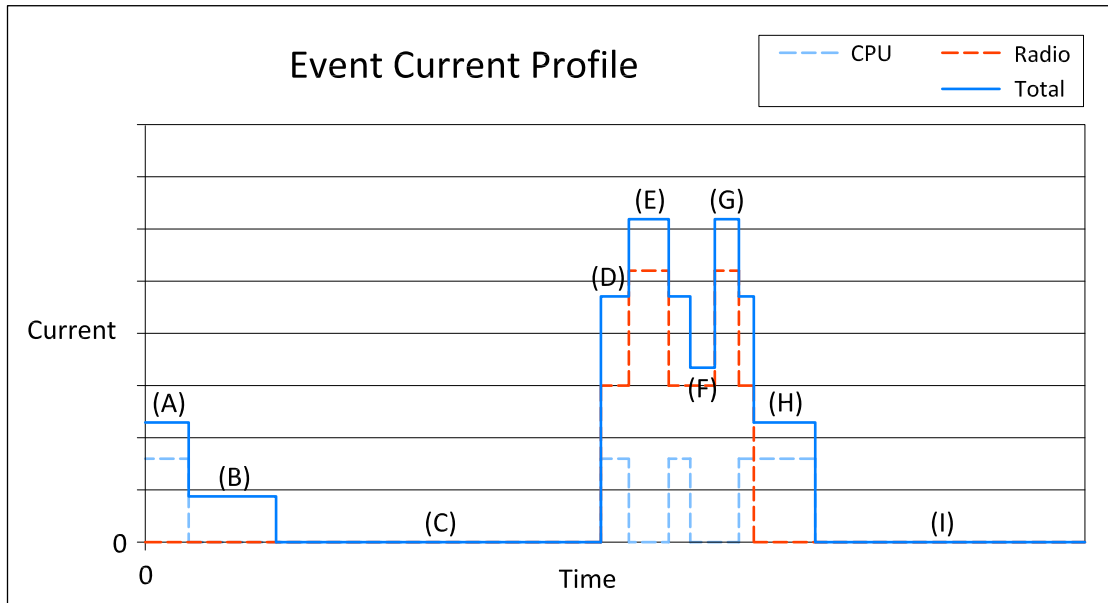
**Figure 56: Scanning event**

**Table 44: Scanning event**

Stage	Description
(A)	Pre-processing (CPU)
(B)	Standby IDLE + HFXO ramp
(C)	Standby
(D)	Radio startup
(E)	Radio RX
(F)	Post-processing (CPU)
(G)	Standby

## 19.4 Central connection event

This section gives an overview of the power profile of the central connection event implemented in the SoftDevice.



**Figure 57: Central connection event**

**Table 45: Central connection event**

Stage	Description
(A)	Pre-processing (CPU)
(B)	Standby + HFXO ramp
(C)	Standby
(D)	Radio startup
(E)	Radio TX
(F)	Radio switch
(G)	Radio RX
(H)	Post-processing (CPU)
(I)	Standby

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## Chapter 20

# SoftDevice identification and revision scheme

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The SoftDevices are identified by the SoftDevice part code, a qualified IC partcode (for example, nRF52832), and a version string.

The identification scheme for SoftDevices consists of the following items:

- For revisions of the SoftDevice which are production qualified, the version string consists of major, minor, and revision numbers only, as described in the table below.
- For revisions of the SoftDevice which are not production qualified, a build number and a test qualification level (alpha/beta) are appended to the version string.
- For example: s110\_nrf51\_1.2.3-4.alpha, where major = 1, minor = 2, revision = 3, build number = 4 and test qualification level is alpha. Additional examples are given in table [Table 47: SoftDevice revision examples](#) on page 88.

**Table 46: Revision scheme**

Revision	Description
Major increments	<p>Modifications to the API or the function or behavior of the implementation or part of it have changed.</p> <p>Changes as per minor increment may have been made.</p> <p>Application code will not be compatible without some modification.</p>
Minor increments	<p>Additional features and/or API calls are available.</p> <p>Changes as per minor increment may have been made.</p> <p>Application code may have to be modified to take advantage of new features.</p>
Revision increments	<p>Issues have been resolved or improvements to performance implemented.</p> <p>Existing application code will not require any modification.</p>
Build number increment (if present)	New build of non-production versions.

**Table 47: SoftDevice revision examples**

Sequence number	Description
s110_nrf51_1.2.3-1.alpha	Revision 1.2.3, first build, qualified at alpha level
s110_nrf51_1.2.3-2.alpha	Revision 1.2.3, second build, qualified at alpha level



Sequence number	Description
s110_nrf51_1.2.3-5.beta	Revision 1.2.3, fifth build, qualified at beta level
s110_nrf51_1.2.3	Revision 1.2.3, qualified at production level

**Table 48: Test qualification levels**

Qualification	Description
Alpha	<ul style="list-style-type: none"> <li>• Development release suitable for prototype application development.</li> <li>• Hardware integration testing is not complete.</li> <li>• Known issues may not be fixed between alpha releases.</li> <li>• Incomplete and subject to change.</li> </ul>
Beta	<ul style="list-style-type: none"> <li>• Development release suitable for application development.</li> <li>• In addition to alpha qualification:               <ul style="list-style-type: none"> <li>• Hardware integration testing is complete.</li> <li>• Stable, but may not be feature complete and may contain known issues.</li> <li>• Protocol implementations are tested for conformance and interoperability.</li> </ul> </li> </ul>
Production	<ul style="list-style-type: none"> <li>• Qualified release suitable for production integration.</li> <li>• In addition to beta qualification:               <ul style="list-style-type: none"> <li>• Hardware integration tested over supported range of operating conditions.</li> <li>• Stable and complete with no known issues.</li> <li>• Protocol implementations conform to standards.</li> </ul> </li> </ul>

## 20.1 MBR distribution and revision scheme

The MBR is distributed in each SoftDevice hex file.

The version of the MBR distributed with the SoftDevice will be published in the release notes for the SoftDevice and uses the same major, minor and revision numbering scheme as described here.

