S120 nRF51

Bluetooth® low energy combined Central and Peripheral SoftDevice

SoftDevice Specification v2.1

Key Features

- *Bluetooth*® 4.1 compliant low energy single-mode protocol stack, initializable at runtime as either Central or Peripheral
    - Central and Observer roles - up to 8 simultaneous connections
    - Peripheral role with a concurrent Broadcaster
    - Link layer
    - L2CAP, ATT, and SM protocols
    - GATT and GAP APIs
    - GATT Client and Server
    - Security Manager including MITM and OOB pairing
- Complementary nRF51 SDK including *Bluetooth* profiles and example applications
- Master Boot Record for over-the-air device firmware update
- Memory isolation between application and protocol stack for robustness and security
- Thread-safe supervisor-call based API
- Asynchronous, event-driven behavior
- No RTOS dependency
    - Any RTOS can be used
- No link-time dependencies
    - Standard ARM® Cortex™-M0 project configuration for application development
- Support for multiprotocol operation
    - Concurrent with the *Bluetooth* stack using concurrent multiprotocol timeslot API
    - Alternate protocol stack running in application stack

Applications

- A4WP wireless charging
- Sports & Fitness devices
    - Sports watches
    - Bike computers

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Document Status

Status	Description
v0.5	This specification contains target specifications for product development.
v0.7	This specification contains preliminary data; supplementary data may be published from Nordic Semiconductor ASA later.
v1.0	This specification contains final product specifications. Nordic Semiconductor ASA reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.

Revision History

Date	Version	Description
January 2015	2.1	**Updated content:** • ***Section 12.3.2 "Initiating interrupt latency"*** on page 47 • ***Section 12.3.3 "Connection Event interrupt latency"*** on page 48 • ***Section 12.3.4 "Connection event CPU availability"*** on page 49
December 2014	2.0	**Added content:** • ***Chapter 8 "Concurrent Multiprotocol Timeslot API"*** on page 20 • ***Section 15.1 "MBR distribution and revision scheme"*** on page 53 • ***Chapter Appendix A "SoftDevice architecture"*** on page 54 **Updated content:** • Front page • ***Chapter 1 "Introduction"*** on page 5 • ***Section 2.2 "Multiprotocol support"*** on page 6 • ***Chapter 3 "Bluetooth low energy protocol stack"*** on page 7 • ***Chapter 7 "Radio Notification"*** on page 16 • ***Chapter 9 "Master Boot Record and Bootloader"*** on page 30 • ***Chapter 10 "SoC resource requirements"*** on page 33 • ***Chapter 11 "Multi-link Central role scheduling"*** on page 38 • ***Chapter 12 "Processor availability and interrupt latency"*** on page 44 • ***Chapter 13 "BLE data throughput"*** on page 50
July 2014	1.1	**Updated content:** • ***Chapter 6 "Flash memory API"*** on page 15

Date	Version	Description
May 2014	1.0	First production release. **Added content:** • ***Section 3.1 "Profile and service support"*** on page 8 • ***Chapter 7 "Flash memory API"*** on page 16 • ***Chapter 8 "Radio Notification"*** on page 18 • ***Chapter 9 "Master Boot Record and Bootloader"*** on page 30 • ***Chapter 14 "BLE power profiles"*** on page 51 **Updated content:** • Front page • ***Section 1.1 "Documentation"*** on page 5 • ***Section 3.1 "Profile and service support"*** on page 8 • ***Section 3.2 "Bluetooth low energy features"*** on page 9 • ***Section 3.3 "Limitations on procedure concurrency"*** on page 12 • ***Chapter 4 "SoC library"*** on page 13 • ***Section 10.2 "Hardware blocks and interrupt vectors"*** on page 34 • ***Chapter 10.4 "Programmable Peripheral Interconnect (PPI)"*** on page 36 • ***Chapter 11 "Multi-link Central role scheduling"*** on page 38 • ***Section 12.2 "Processor availability"*** on page 45 • ***Section 12.3.3 "Connection Event interrupt latency"*** on page 48 • ***Chapter 13 "BLE data throughput"*** on page 50
November 2013	0.5	Preliminary release.

1 Introduction

The S120 SoftDevice is a Bluetooth® low energy (BLE) combined Central and Peripheral protocol stack solution. That is, the SoftDevice can be initialized to run either as a Central protocol stack or as a Peripheral protocol stack. When initialized as a Central, it supports up to eight simultaneous Central role connections and an Observer. When initialized as a Peripheral, is supports a Peripheral connection and a concurrent Broadcaster. The SoftDevice integrates a low energy controller and host, and provides a full and flexible Application Programming Interface (API) for building Bluetooth low energy System on Chip (SoC) solutions.

This document contains information about the S120 SoftDevice memory and resource requirements. It also describes the performance and BLE features of the SoftDevice when configured as a Central. For BLE features and functionality when configured as a Peripheral, see the S110 SoftDevice Specification.

Note: The SoftDevice features and performance are subject to change between revisions of this document. See ***Section 15.2 "Notification of SoftDevice revision updates"*** on page 53 for more information. This specification outlines the supported features of a production level SoftDevice. Alpha and beta versions of the SoftDevice may not support all features. To find information on any limitations or omissions, see the SoftDevice release notes, which will contain a detailed summary of the release status.

1.1 Documentation

Below is a list of the core documentation for the SoftDevice.

Document	Description
Appendix A: SoftDevice Architecture	Essential reading for understanding the resource usage and performance related chapters of this document.
nRF51822 Product Specification (PS)	Contains a description of the hardware, modules, and electrical specifications specific to the nRF51822 chip.
nRF51822 Product Anomaly Notification (PAN)	Contains information on anomalies related to the nRF51822 chip.
nRF51 Series Compatibility Matrix	Compatibility and relations between nRF51 IC revisions, SoftDevices and SoftDevice Specifications, SDKs, development kits, documentation, and QDIDs.
Bluetooth Core Specification	The *Bluetooth Core Specification* version 4.1, Volumes 1, 3, 4, and 6 describes *Bluetooth* terminology which is used throughout the SoftDevice Specification.

2 Product overview

This section provides an overview of the SoftDevice.

2.1 SoftDevice

The SoftDevice is a precompiled and linked binary software implementing a *Bluetooth* 4.1 low energy protocol stack for the nRF51 series of chips. See the nRF51 Series Compatibility Matrix for SoftDevice/chip compatibility information.

The Application Programming Interface (API) is a standard C language set of functions and data types that give the application complete compiler and linker independence from the SoftDevice implementation.

The SoftDevice enables the application programmer to develop their code as a standard ARM® Cortex™-M0 project without needing to integrate with proprietary chip-vendor software frameworks. This means that any ARM® Cortex™-M0 compatible toolchain can be used to develop *Bluetooth* low energy applications with the SoftDevice.

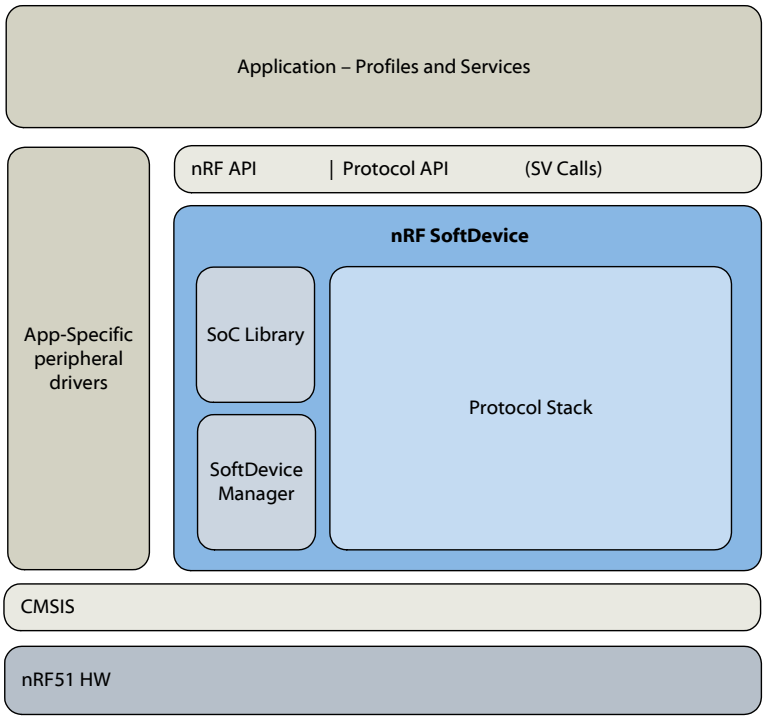


Figure 1 *System on Chip application with the SoftDevice*

The SoftDevice can be programmed onto compatible nRF51 Series chips during both development and production.

2.2 Multiprotocol support

The SoftDevice supports both non-concurrent and fully concurrent multiprotocol implementations. 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. For concurrent multiprotocol operation, with a proprietary protocol running concurrently with the SoftDevice protocol(s), see ***Chapter 8 "Concurrent Multiprotocol Timeslot API"*** on page 20.

3 *Bluetooth* low energy protocol stack

The *Bluetooth* 4.1 compliant low energy Host and Controller embedded in the SoftDevice are fully qualified with multi-role support (Central and Observer or Peripheral and Broadcaster). The API is defined above the Generic Attribute Protocol (GATT), Generic Access Profile (GAP), and Logical Link Control and Adaptation Protocol (L2CAP). The SoftDevice allows applications to implement standard *Bluetooth* low energy profiles as well as proprietary use case implementations.

The nRF51 Software Development Kit (SDK) complements the BLE protocol stack with Service and Profile implementations. Single-mode System on Chip (SoC) applications are enabled by the full BLE protocol stack and nRF51 series integrated circuit (IC).

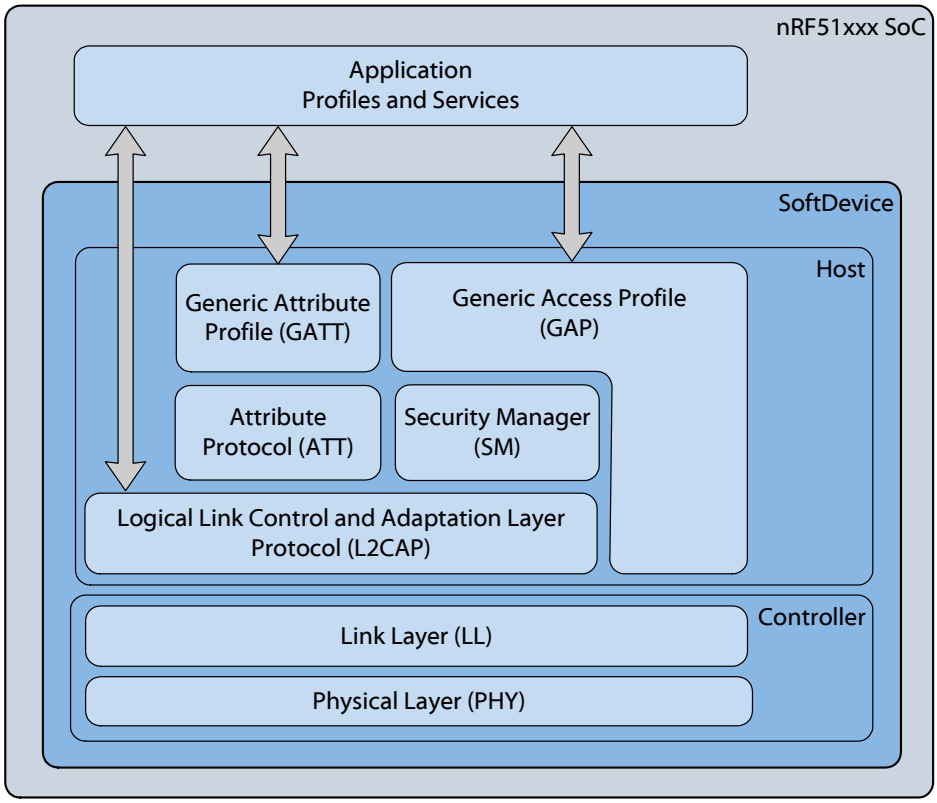


Figure 2 *SoftDevice stack architecture*

3.1 Profile and service support

Table 1 lists the profiles and services adopted by the *Bluetooth* Special Interest Group at the time of publication of this document. The SoftDevice supports all of these as well as additional proprietary profiles.

Adopted Profile	Adopted Services
HID over GATT	HID Battery Device Information
Heart Rate	Heart Rate Device Information
Proximity	Link Loss Immediate Alert TX Power
Blood Pressure	Blood pressure
Health Thermometer	Health Thermometer
Glucose	Glucose
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
Continuous Glucose Meter	Continuous Glucose Bond Management
Time	Current Time Next DST change Reference Time Update

Table 1 *Supported profiles and services*

Note: Examples for selected profiles and services are available in the nRF51 SDK. See the SDK documentation for details.

3.2 *Bluetooth* 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* 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, pairing, and bonding.

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

API Features	Description
Interface to: GATT/GAP	Consistency between APIs including shared data formats.
Attribute Table population and access	Full flexibility to populate the Attribute Table at runtime, 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 2 *Central role API features in the BLE stack*

GAP Features	Description
Multi-role: Central and Observer	Up to 8 concurrent links supported as a Central. Observer can run concurrently with a central in a connection.
Procedure Queueing across links	Connection Parameter Update and Encryption procedures are automatically queued by GAP to be executed sequentially on multiple links.
Multiple bond support	Keys and peer information stored in application space. No restrictions in stack implementation.
Security mode 1: Levels 1, 2, and 3	Support for all levels of SM 1 independently per link.

Table 3 *Central role GAP features in the BLE stack*

GATT Features	Description
Full GATT Server	Support for 8 concurrent ATT server sessions
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 Support for 8 concurrent ATT client sessions
Implemented GATT Sub-procedures	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 Write Without Response Write Characteristic Value Notifications Indications Read Characteristic Descriptors Read Long Characteristic Descriptors Write Characteristic Descriptors Write Long Characteristic Values Write Long Characteristic Descriptors Reliable Writes

Table 4 *Central role GATT 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, Passkey Entry, and Out of Band	API provides the application full control of the pairing sequences.

Table 5 *Central role Security Manager (SM) 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.
Max MTU size 23 bytes	Up to 20 bytes of user data available per packet.

Table 6 *Central role Attribute Protocol (ATT) 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 though the initiator is not available at that time.
Master connection parameter update	
Channel map configuration	Setup of channel map for all connections from the application.
Encryption	
RSSI	Signal strength measurements both during scanning and connection.

Table 7 *Central role Controller, Link Layer (LL) features in the BLE stack*

Proprietary Feature	Description
TX Power control	Access for the application to change TX power settings anytime.
Enhanced Privacy 1.1 support	Synchronous and low power solution for BLE enhanced privacy with hardware-accelerated address resolution for whitelisting.
Master Boot Record (MBR) for Device Firmware Update (DFU)	Enables over-the-air SoftDevice replacement, giving full SoftDevice update capability.

Table 8 *Central role proprietary features in the BLE stack*

3.3 Limitations on procedure concurrency

When there are multiple connections in the Central role, the concurrency of protocol procedures will have some limitations. The Host instantiates both GATT and GAP server 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.

The limitations are outlined in ***Table 9*** below.

Protocol procedures	Limitation with multiple connections active
GATT	None. All procedures can be executed in parallel.
GAP	None. All procedures can be executed in parallel. Note that some GAP procedures require LL 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, that is, each SM procedure must run to completion before the next procedure begins across all connections. For example sd_ble_gap_authenticate().
LL	The LL Disconnect procedure has no limitations and can be executed on any, or all links simultaneously. The LL connection parameter update and encryption establishment procedures can only execute on one link at a time.

Table 9 *Central role procedure concurrency*

4 SoC library

The following features ensure the Application and SoftDevice coexist with safe sharing of common SoC resources.

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	Gives the application access to all NVIC features without corrupting SoftDevice configurations.
Rand	Provides random numbers from the hardware random number generator.

Power	Access to POWER block configuration while the SoftDevice is enabled:
	• Access to RESETREAS register
	• Set power modes
	• Configure power fail comparator
	• Control RAM block power
	• Use general purpose retention register
	• Configure DC/DC converter state:
	  • DISABLED
	  • ENABLED

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 event.
PPI	Configuration interface for PPI channels and groups reserved for an application.
Concurrent Multiprotocol Timeslot API	Schedule other radio protocol activity, or periods of radio inactivity. See ***Chapter 8 "Concurrent Multiprotocol Timeslot API"*** on page 20.
Radio notification	Configure Radio Notification signals on ACTIVE and/or nACTIVE. See ***Chapter 8 "Radio Notification"*** on page 18.
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 ***Chapter 6 "Flash memory API"*** on page 15.
Temperature	Application access to the temperature sensor.

Table 10 *System on Chip features*

5 SoftDevice Manager

The following feature enables the Application to manage the SoftDevice on a top level.

Feature	Description
SoftDevice control API	Control of SoftDevice state through enable and disable. On enable, the low frequency clock source can be selected between the following options: • RC oscillator • Crystal oscillator

Table 11 *SoftDevice Manager*

6 Flash memory API

Asynchronous flash memory operations are performed using the SoC library API and provide the application with flash write, flash erase, and flash protect support through the SoftDevice. This interface can safely be used during active BLE connections.

The flash memory access is scheduled in between the protocol radio events. For short connection or scan intervals, the time required for the flash memory access may be larger than the connection or scan interval. In this case, protocol radio events may be skipped. The flash memory access may also be delayed to minimize the disturbance of the BLE radio protocol.

If the protocol radio events are in a certain critical state, flash memory access may get delayed for a long period resulting in the timeout event `NRF_EVT_FLASH_OPERATION_ERROR`. If this happens, retry the flash memory operation. Examples of typical critical phases of protocol radio events include: connection setup, connection update, disconnection, and just before supervision timeout.

The probability of successfully accessing the flash memory is higher when there is little BLE activity. For example, with long connection intervals there will be a higher probability of accessing flash memory successfully. Use the guidelines in ***Table 12*** to improve the probability of flash operation success.

Note: Flash page erase takes approximately 22 ms and a 256 byte flash write takes approximately 13 ms.

Table 12 describes the probability of flash write and erase operations succeeding using some example BLE activity and configuration criteria:

BLE activity	Flash write/erase
8 BLE central connections BLE scanner All active links fulfill the following criteria: Supervision timeout > 6* connection interval	Low to medium probability of flash operation success. Probability of success increases with increase in connection interval and decrease in scan window.
8 BLE central connections No BLE scanner All active links fulfill the following criteria: Supervision timeout > 6* connection interval Connection interval >= 50 ms All links have equal connection interval	High probability of flash operation success.
No BLE central connection No BLE scanner	Flash operation will always succeed.

Table 12 *Behavior with central side BLE traffic and concurrent flash write/erase*

7 Radio Notification

Radio Notification is a configurable feature that enables ACTIVE and INACTIVE (nACTIVE) signals from the SoftDevice to the application notifying when the radio is in use. The signal is sent using software interrupt, as specified in ***Table 22*** on page 36.

The ACTIVE signal, if enabled, is sent before the Radio Event starts. The nACTIVE signal is sent at the end of the Radio Event. These signals can be used by the application programmer to synchronize application logic with Radio activity and packet transfers. For example, the ACTIVE signal can be used to shut off external devices to manage peak current drawn during periods when the radio is on, or to trigger sensor data collection for transmission in the Radio Event.

The following figures show the radio notification signal in relation to different combinations of active links and scanning events. See ***Table 13*** on page 18 for a description of the notations used in text and figures and ***Chapter 11 "Multi-link Central role scheduling"*** on page 38 to understand the scheduling of links and scanner.

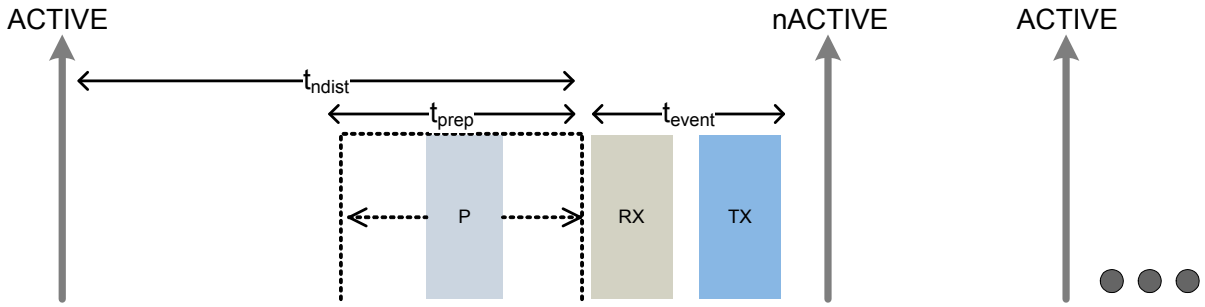


Figure 3 *BLE Radio Notification in relation to a single active link*

To ensure the notification signal is available to the application at the configured time when a single link is established, the following rule must be followed:

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

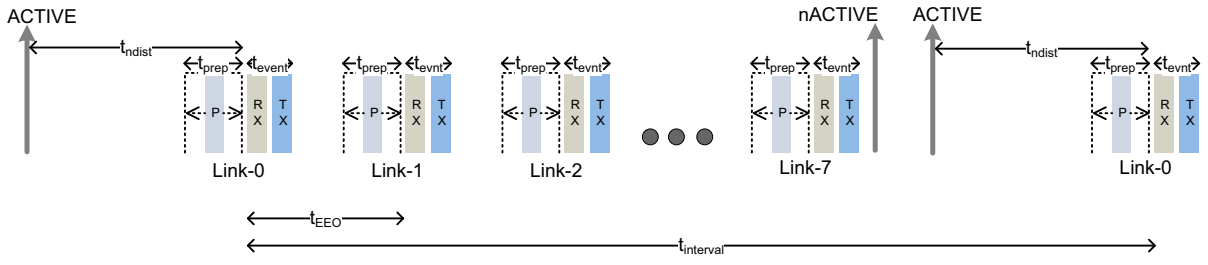


Figure 4 *BLE Radio Notification signal in relation to 8 active links*

To ensure the notification signal is available to the application at the configured time when 8 links are established, the following rule must be followed:

$$t_{ndist} + 8 \times t_{EEO} < t_{interval}$$

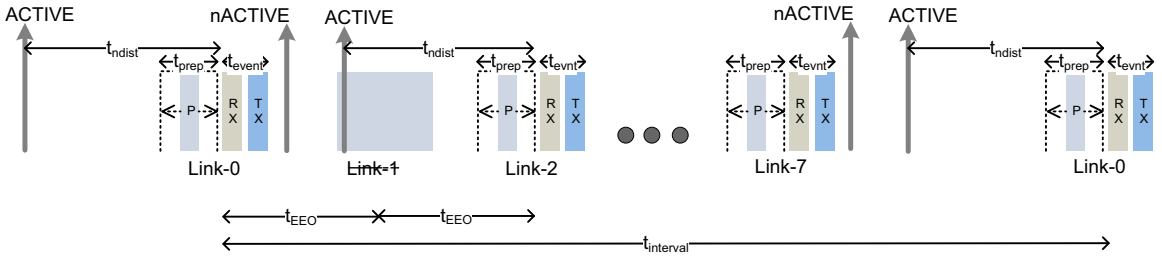


Figure 5 *BLE Radio Notification signal when the number of active links is greater than 1 but less than 8*

To ensure the notification signal is available to the application in the gap left by inactive links, the gap should be greater than t_{ndist}. This can be expressed as (where $n_{inactive}$ is the number of consecutive inactive links):

$$n_{inactive} \times t_{EEO} > t_{ndist}$$

For example, the case shown in ***Figure 5*** where link-1 is not connected, a gap of t_{EEO} exists between two links so active signal will come if:

$$t_{EEO} > t_{ndist}$$

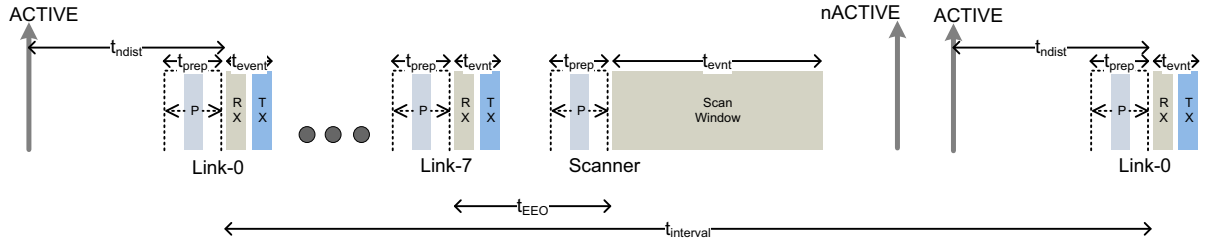


Figure 6 *BLE Radio Notification signal in relation to 8 active links and running scanner*

To ensure the notification signal is available to the application at the configured time with 8 links established and a scanner started, the following rule must be followed:

$$t_{ndist} + 9 \times t_{EEO} + \text{Scan\_window} < t_{interval}$$

Table 13 describes the notation used in the figures in this section.

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	CPU processing in the lower stack interrupt between ACTIVE and RX.	The CPU processing may occur anytime, up to t_{prep} before RX.
RX	Reception of packet.	
TX	Transmission of packet.	
t_{ndist}	The notification distance - the time between ACTIVE and first RX/TX in a Radio Event.	This time is configurable by the application developer.
t_{event}	The time used in a Radio Event.	
t_{prep}	The time before first RX/TX to prepare and configure the radio.	The application will be interrupted by the LowerStack during t_{prep}. **Note**: All packet data to send in an event should be sent to the stack t_{prep} before the Radio starts.
t_P	Time used for preprocessing before the Radio Event.	
$t_{interval}$	Time between Radio Events as per the protocol.	
t_{EEO}	Time between Radio Events (Event-to-Event Offset).	The time between the start of adjacent connections, and between the last connection and the scanner. Some or all connections and/or the scanner may be idle.

Table 13 *Radio Notification figure labels*

Table 14 shows the ranges of the timing symbols in the figures in this section.

Value	Range (µs)
t_{ndist}	800, 1740, 2680, 3620, 4560, 5500 (Configured by the application)
t_{event}	Refer to ***Section 12.2 "Processor availability"*** on page 45
t_{prep}	165 to 1550
t_P	Refer to ***Section 12.2 "Processor availability"*** on page 45
t_{EEO}	2000 to 2250

Table 14 *BLE Radio Notification timing ranges*

Using the numbers from ***Table 14***, the amount of CPU time available between the ACTIVE signal and a Radio Event is:

$$t_{ndist} - t_P$$

The following equation shows the amount of time before stack prepare interrupt after ACTIVE signal. Data packets must be transferred to the stack using the API within this time from the ACTIVE signal if they are to be sent in the next Radio Event.

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

Note: 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} should be set greater than 1500.

8 Concurrent Multiprotocol Timeslot API

The Multiprotocol Timeslot API allows an application developer to safely schedule 2.4 GHz proprietary radio usage while the SoftDevice protocol stack is in use by the device. This allows the nRF51 device to be part of a network using the SoftDevice protocol stack and an alternative network of wireless devices at the same time.

The Timeslot feature gives the application access to the radio and other restricted peripherals, which it does by queueing 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 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 is granted, the application has exclusive and real-time access to the normally blocked RADIO, TIMER0, CCM, AAR, and PPI (channels 14 – 15) peripherals and can use these freely for the length of the timeslot, see ***Table 20 "Hardware access type definitions"*** on page 34 and ***Table 21 "Peripheral protection and usage by SoftDevice"*** on page 35.

8.1 Request types

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. Timeslots may also be requested at a given time. 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. Note that the first request in a session must always be *earliest possible* to create the timing reference point for later timeslots. The application may also request to extend an on-going 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.

8.2 Request priorities

Timeslots can be requested at either high or normal priority, indicating how important it is for the application to access the specified peripheral. Using normal priority should be considered best practice to minimize the influence of the use of the Multiprotocol Timeslot API on other activities. The high priority should only be used when required, such as for running a radio protocol with certain timing requirements that are not met using normal priority.

8.3 Timeslot length

The length of the timeslot is specified by the application in the request and ranges from 100 µs to 100 ms. Longer continuous timeslots can be achieved by requesting to extend the current timeslot. Successive extensions will give a timeslot as long as possible within the limits set by other SoftDevice activities, up to a maximum of 128 s.

8.4 Scheduling

Timeslots requested by the application are scheduled within the SoftDevice along with the SoftDevice protocol and the Flash API activities.

Whether the timeslot request is granted and access to the peripherals given is based on when the request was made, when the timeslot is wanted, the priority of the request, and the requested length of the timeslot. If the requested timeslot does not collide with other activities, the request will be granted and the timeslot scheduled. If the requested timeslot collides with an already scheduled activity with equal or higher priority, the request will be blocked. If a later arriving activity of higher priority causes a collision, the request will be canceled and the scheduled timeslot revoked. However, a timeslot that has already started cannot be interrupted or canceled. Timeslots requested at high priority will cancel other activities scheduled at lower priorities in case of a collision. Also, 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.

Note: Radio Notification signals behave the same way for timeslots requested through the Multiprotocol Timeslot interface as for SoftDevice internal activities, see ***Chapter 8 "Radio Notification"*** on page 18 for more information. If Radio Notifications are enabled, Multiprotocol Timeslots will be notified.

8.5 Performance considerations

Since the Multiprotocol Timeslot API shares core peripherals with the SoftDevice, and are scheduled along with other SoftDevice activities, use of the Timeslot feature may influence SoftDevice performance. Therefore the application configuration of the SoftDevice protocol should be considered when using the Multiprotocol Timeslot API.

In general, all timeslot requests should use the lowest priority to ensure that interruptions to other activity is minimized. In addition, timeslots should be kept as short as possible in order to minimize the impact on the overall performance of the device. Similarly, requesting a shorter timeslot and then extending it gives more flexibility to schedule other activities than requesting a longer timeslot.

8.6 Multiprotocol 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.

Note: 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.

8.6.1 API calls

The following API calls are defined:

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

***Table 15** API calls*

8.6.2 Timeslot events

Events come from the SoftDevice scheduler and are used for timeslot session management. Events are received in the application event handler callback function, which will typically be run in App(L) priority, see ***Section 12.2 "Processor availability"*** on page 45.

The following events are defined:

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 preempted by higher priority activity.
NRF_EVT_RADIO_SIGNAL_ CALLBACK_INVALID_RETURN	Signal handler: The last signal hander return value contained invalid parameters.

***Table 16** Timeslot events*

8.6.3 Timeslot signals

Signals come from the peripherals and arrive within a timeslot. Signals are received in a signal handler callback function that the application must provide. The signal handler runs in LowerStack priority, which is the highest priority in the system, see ***Section 12.2 "Processor availability"*** on page 45.

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 *nRF51 Reference Manual*.
NRF_RADIO_CALLBACK_SIGNAL_TYPE_TIMER0	Timer interrupt, for more information, see chapter *Timer/counter (TIMER)* in the *nRF51 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.

Table 17 *Timeslot signals*

8.6.4 Signal handler return actions

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

Return value	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.

Table 18 *Signal handler action return values*

8.6.5 Ending a timeslot in time

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

8.6.6 The signal handler runs at LowerStack priority

The signal handler runs at LowerStack priority, which is the highest priority. Therefore, it cannot be interrupted by any other activity. Also, as for the App(H) interrupt, SVC calls are not available in the signal handler. 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 the real time signal handling. When a signal has been handled, exit the signal handler to wait for the next signal. Processing other than signal handling should be run at lower priorities, outside of the signal handler.

8.7 Timeslot usage examples

In this section we provide several timeslot usage examples and describe the sequence of events within them.

8.7.1 Complete session example

Figure 7 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*). The SoftDevice schedules the timeslot. At the start of the timeslot, the SoftDevice calls the application signal hander 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 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.

The following timeslots (the middle timeslot in ***Figure 7***) are all similar. 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, 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.

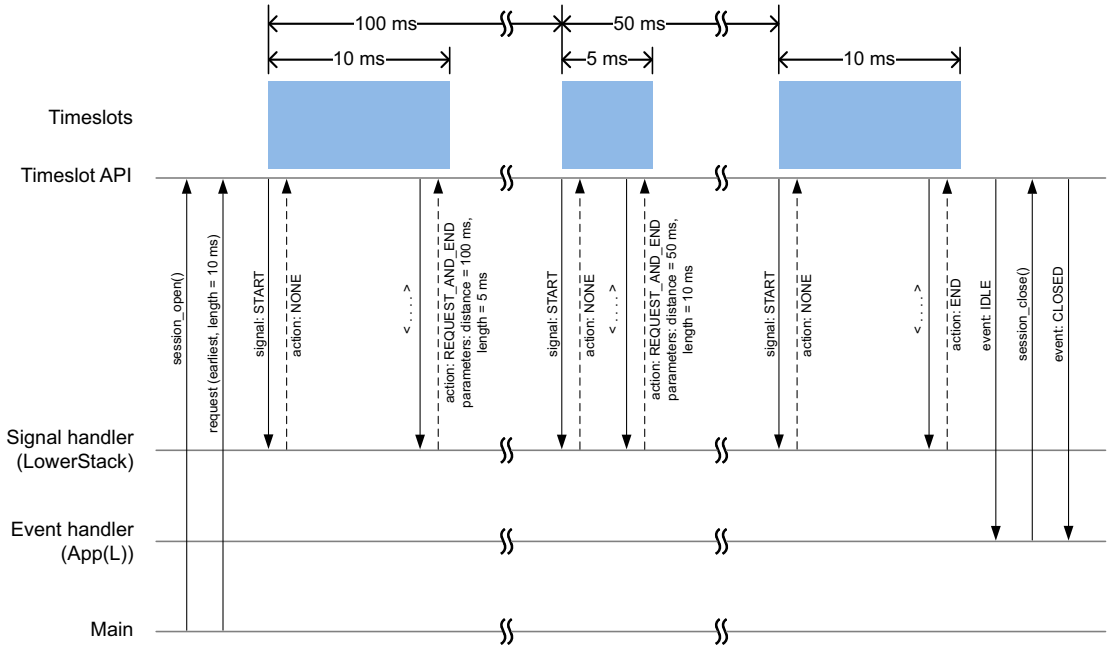


Figure 7 *Complete session example*

8.7.2 Blocked timeslot example

Figure 8 shows a situation in the middle of a session where a requested timeslot cannot be scheduled. At the end of the first timeslot in ***Figure 8***, 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 further out in time. This request succeeds (it does not collide with anything), and a new timeslot is scheduled.

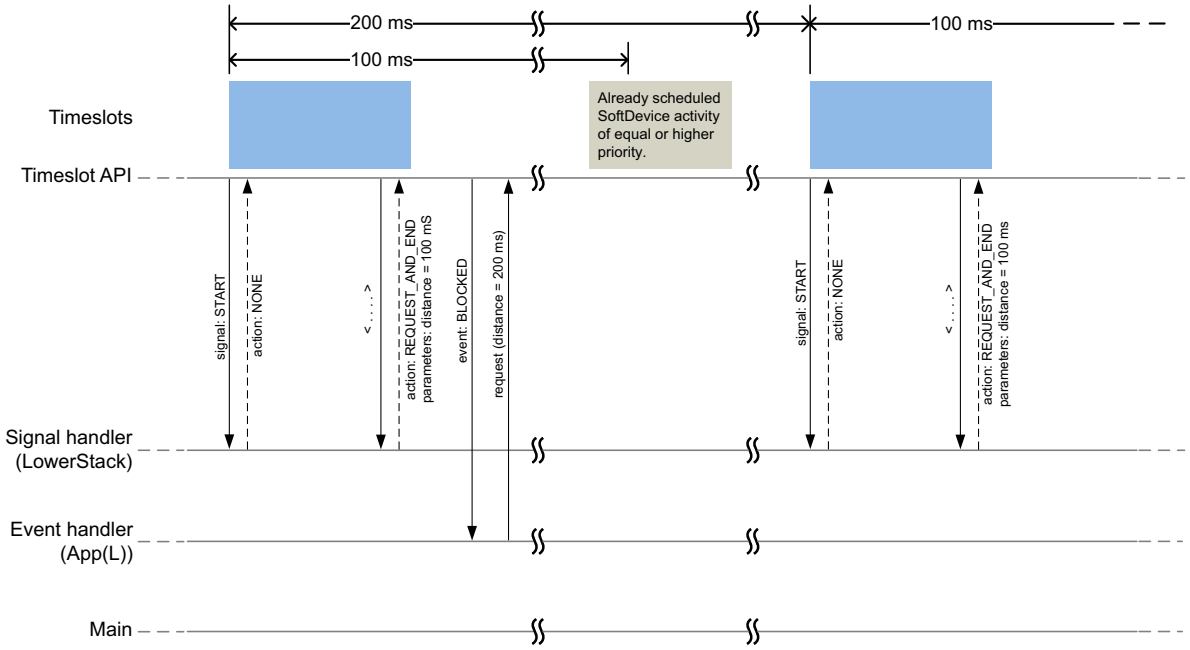


Figure 8 *Blocked timeslot example*

8.7.3 Canceled timeslot example

Figure 9 on page 28 shows a situation in the middle of a session where a requested and scheduled application timeslot is being revoked. The upper part of ***Figure 9*** on page 28 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 been started yet, it is still some time into the future. The lower part of ***Figure 9*** on page 28 shows the situation some time later. In the meantime, time for a SoftDevice activity of higher priority has been requested internally in the SoftDevice, at a time which collides with the scheduled application timeslot. To accommodate the higher priority request, the application timeslot has been removed from the schedule, and the higher priority SoftDevice activity scheduled instead. The application is notified about this by a CANCELED event to the application event handler. The application then makes a new request further out in time. This request succeeds (it does not collide with anything), and a new timeslot is scheduled.

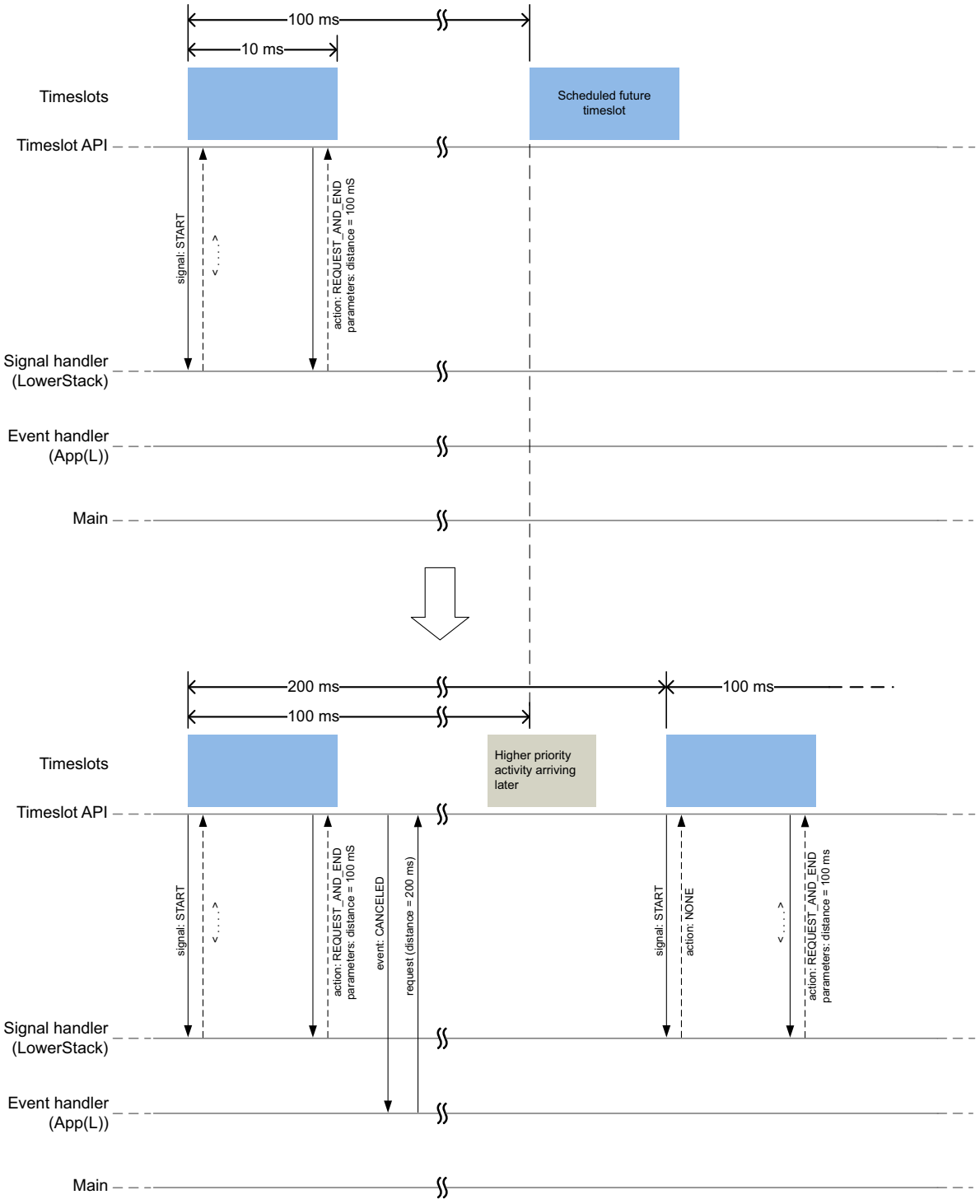


Figure 9 *Canceled timeslot example*

8.7.4 Timeslot extension example

Figure 10 shows how an application can use 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 slot in ***Figure 10***, 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 at extending the timeslot fails, as a further extension would cause a collision with a SoftDevice activity that has been scheduled. Therefore the application does 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.

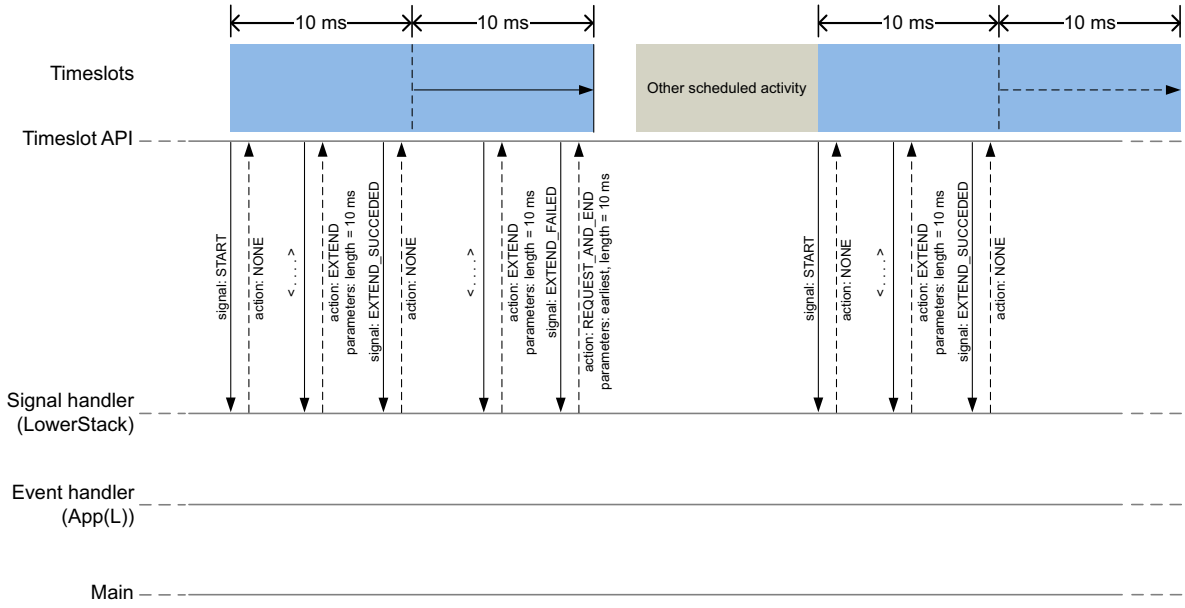


Figure 10 *Timeslot extension example*

9 Master Boot Record and Bootloader

The SoftDevice supports the use of a bootloader. A bootloader may be used to update the firmware on the chip. The SoftDevice also contains a Master Boot Record (MBR). 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.

9.1 Master Boot Record

The Master Boot Record (MBR) module occupies a defined region in flash memory where the System Vector table resides. All exceptions (reset, hard fault, interrupts, SVC) are processed first by the MBR and then forwarded to appropriate handlers (for example bootloader or SoftDevice). The main feature of the MBR is to provide an interface to allow in-system updates of the SoftDevice and bootloader firmware. The MBR is not updated between versions of the SoftDevice, meaning that during an update process, the MBR is never erased. The MBR ensures safe restart of any ongoing update process if an unexpected reset occurs.

9.2 Bootloader

A bootloader may be used to handle in-system update procedures. The bootloader has access to the full SoftDevice API and can be implemented just as any application that uses a SoftDevice. In particular, the bootloader can make use of the SoftDevice API to enable protocol stack interaction.

The bootloader is supported in the SoftDevice architecture by using a configurable base address for the bootloader in application code space. The base address is configured by setting the UICR.BOOTLOADERADDR 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 SoftDevice. If an unexpected reset occurs during an update of the SoftDevice, it is the responsibility of the bootloader to detect this and recover.

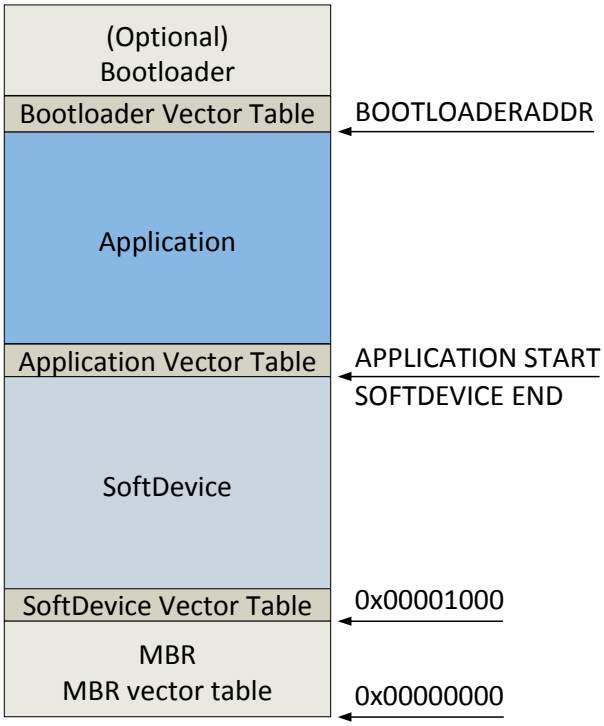


Figure 11 *MBR, SoftDevice, and bootloader architecture*

9.3 Master Boot Record (MBR) and SoftDevice reset behavior

Upon system reset, the MBR Reset Handler is run as specified by the System Vector table. The MBR and SoftDevice reset behavior is as follows:

- If an in-system bootloader update procedure is in progress:
  - Then in-system update procedure is run to completion.
  - System is reset.
- Else if SD_MBR_COMMAND_VECTOR_TABLE_BASE_SET has been called previously:
  - Forward interrupts to the parameter given.
  - Run from Reset Handler (defined in vector table at parameter given).
- 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 SoftDevice.
  - Run SoftDevice Reset Handler (defined in SoftDevice vector table at 0x00001000).
  - In this case, APPLICATION START is hardcoded inside the SoftDevice.
  - SoftDevice run Application Reset Handler (defined in application vector table at APPLICATION START).
- Else system startup error:
  - Sleep forever.

9.4 Master Boot Record (MBR) and SoftDevice initialization

The SoftDevice can be enabled by the bootloader by performing the following in this order:

1. Issue command for MBR to forward interrupts to the SoftDevice using sd_mbr_command() with SD_MBR_COMMAND_INIT_SD.
2. Issue 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. Enable SoftDevice using sd_softdevice_enable().

For a bootloader to transfer execution from itself to the application, the following can be performed:

1. If interrupts have not been forwarded to SoftDevice, issue command for MBR to forward interrupts to SoftDevice using sd_mbr_command() with SD_MBR_COMMAND_INIT_SD.
2. Ensure SoftDevice is disabled using sd_softdevice_disable().
3. Issue command for the SoftDevice to forward interrupts to the application using sd_softdevice_vector_table_base_set(uint32_t address) with APPLICATION_START as parameter.
4. Branch to application's reset handler after reading the handler from the Application Vector Table.

10 SoC resource requirements

The SoftDevice and MBR are designed to be installed on a System on Chip (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 chip including RAM and hardware peripherals like the radio. This chapter describes how the MBR and SoftDevice uses resources. The SoftDevice requirements are shown both when enabled and disabled.

10.1 Memory resource map and usage

The memory map for program memory and RAM at run time with the SoftDevice enabled is illustrated in ***Figure 12*** below. Memory resource requirements, both when the SoftDevice is enabled and disabled, are shown in ***Table 19*** on page 34. Note the definitions of Region 0 (R0) and Region 1 (R1) are valid only when the CLENR0 and RLENR0 registers are optionally programmed to enable memory protection. See the MPU chapter in the *nRF51 Reference Manual* for more details.

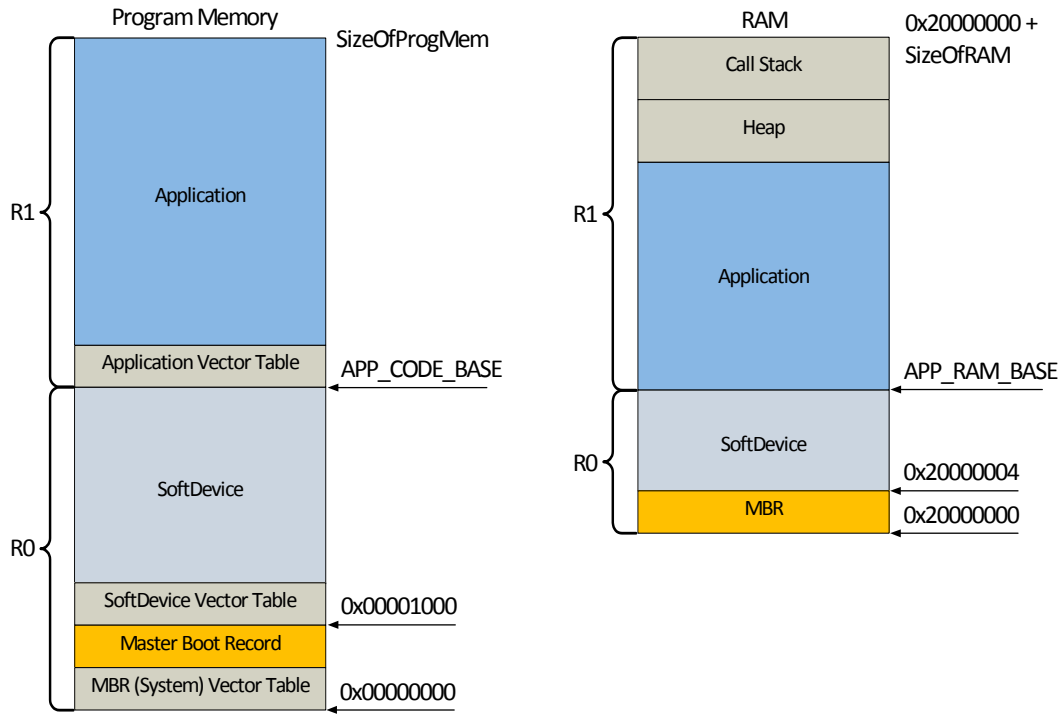


Figure 12 *Memory resource map*

Flash	S120 Enabled	S120 Disabled
SoftDevice MBR	112 kB[1] 4 kB	112 kB 4 kB
APP_CODE_BASE	0x0001D000	0x0001D000

RAM	S120 Enabled	S120 Disabled
SoftDevice MBR	10236 bytes (10 kB - 4 bytes) 4 bytes	4 bytes 4 bytes
APP_RAM_BASE	0x20002800	0x20000008

Call stack[2]	S120 Enabled	S120 Disabled
Maximum usage	1536 bytes (0x600)	0 bytes (0x00)

Heap	S120 Enabled	S120 Disabled
Maximum allocated bytes	0 bytes (0x00)	0 bytes (0x00)

1. 1 kB = 1024 bytes.
2. This is only the call stack used by the SoftDevice at run time. The application call stack memory usage must be added for the total call stack size to be set in the user application.

Table 19 *S120 Memory resource requirements*

10.2 Hardware blocks and interrupt vectors

Table 20 defines access types used to indicate the availability of hardware blocks to the application. ***Table 21*** on page 35 specifies the access the application has, per hardware block, both when the SoftDevice is enabled and disabled.

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

Table 20 *Hardware access type definitions*

ID	Base address	Instance	Access (SoftDevice enabled)	Access (SoftDevice disabled)
0	0x40000000	MPU	Restricted	Open
0	0x40000000	POWER	Restricted	Open
0	0x40000000	CLOCK	Restricted	Open
1	0x40001000	RADIO	Blocked[1]	Open
2	0x40002000	UART0	Open	Open
3	0x40003000	SPI0/TWI0	Open	Open
4	0x40004000	SPI1/TWI1/SPIS1	Open	Open
		...		
6	0x40006000	GPIOTE	Open	Open
7	0x40007000	ADC	Open	Open
8	0x40008000	TIMER0	Blocked[1]	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[1]	Open
15	0x4000F000	AAR	Blocked[1]	Open
16	0x40010000	WDT	Open	Open
17	0x40011000	RTC1	Open	Open
18	0x40012000	QDEC	Open	Open
19	00x4001300	LCOMP	Open	Open
20	0x40014000	Software interrupt	Open	Open
21	0x40015000	Radio Notification	Restricted[2]	Open
22	0x40016000	SoC Events	Blocked	Open
23	0x40017000	Software interrupt	Blocked	Open
24	0x40018000	Software interrupt	Blocked	Open
25	0x40019000	Software interrupt	Blocked	Open
		...		
30	0x4001E000	NVMC	Restricted	Open
31	0x4001F000	PPI	Open[3]	Open
NA	0x50000000	GPIO P0	Open	Open
NA	0xE000E100	NVIC	Restricted[4]	Open

1. Available to the application in Multiprotocol Timeslot API timeslots, see ***Chapter 8 "Concurrent Multiprotocol Timeslot API"*** on page 20.
2. Blocked only when radio notification signal is enabled. See ***Table 22*** on page 36 for software interrupt allocation.
3. See ***Section 10.4 "Programmable Peripheral Interconnect (PPI)"*** on page 36 for limitations on the use of PPI when the SoftDevice is enabled.
4. 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.

Table 21 *Peripheral protection and usage by SoftDevice*

10.3 Application signals - software interrupts

Software interrupts are used by the SoftDevice to signal a change in events. ***Table 22*** shows the allocation of software interrupt vectors to SoftDevice signals.

Software interrupt (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	LowerStack processing - not user configurable.
5	25	UpperStack signaling - not user configurable.

Table 22 *Software interrupt allocation*

10.4 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 CMSIS directly.

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 are in use by the SoftDevice. This is described in ***Table 23***.

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.

PPI channel allocation	SoftDevice enabled	SoftDevice disabled
Application	Channels 0 - 13	Channels 0 - 15
SoftDevice	Channels 14 - 15[1]	-
Preprogrammed channels	**SoftDevice enabled**	**SoftDevice disabled**
Application	-	Channels 20 - 31
SoftDevice	Channels 20 - 31	-
PPI group allocation	**SoftDevice enabled**	**SoftDevice disabled**
Application	Groups 0 - 1	Groups 0 - 3
SoftDevice	Groups 2 - 3	-

1. Available to the application in Multiprotocol Timeslot API timeslots, see ***Chapter 8 "Concurrent Multiprotocol Timeslot API"*** on page 20.

Table 23 *PPI channel and group availability*

10.5 SVC number ranges

Table 24 shows which SVC numbers an application program can use and which numbers are used by the SoftDevice.

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

SVC number allocation	SoftDevice enabled	SoftDevice disabled
Application	0x00-0x0F	0x00-0x0F
SoftDevice	0x10-0xFF	0x10-0xFF

Table 24 *SVC number allocation*

10.6 External requirements

For correct operation of the SoftDevice, it is a requirement that the 16 MHz crystal oscillator (16 MHz XOSC) startup time is less than 1.5 ms. The external clock crystal and other related components must be chosen accordingly. Data for the device XOSC input can be found in the product specification for the device.

11 Multi-link Central role scheduling

The S120 stack supports up to eight Central role connections and an Observer or Scanner simultaneously. An Initiator can only be started if there are less than eight Central role connections established running.

11.1 Connection timing

The link scheduling system in the S120 SoftDevice adds Central link events relative to the first connected link. ***Figure 13*** shows a scenario where there are two links established. C0 events corresponds to the first Central connection made and C1 events corresponds to the second connection made. C1 events are initially offset from C0 events by t_{EEO} milliseconds. C1 events, in this example, have exactly double the connection interval of C0 events (the connection intervals have a common factor which is "connectionInterval 0"), so the events remain forever offset by t_{EEO} ms.

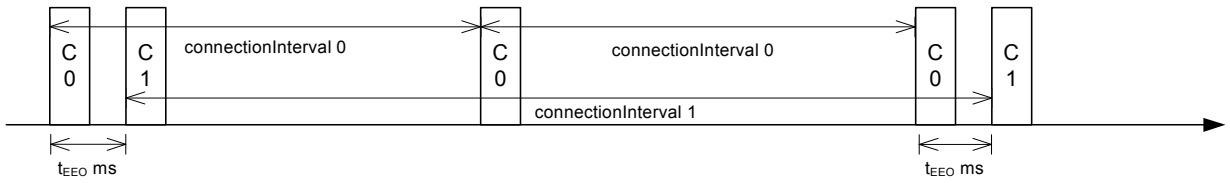


Figure 13 *Multi-link scheduling - one or more connections, factored intervals*

In ***Figure 14*** 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 event shown for C1 is dropped because it collides with the C0 event.

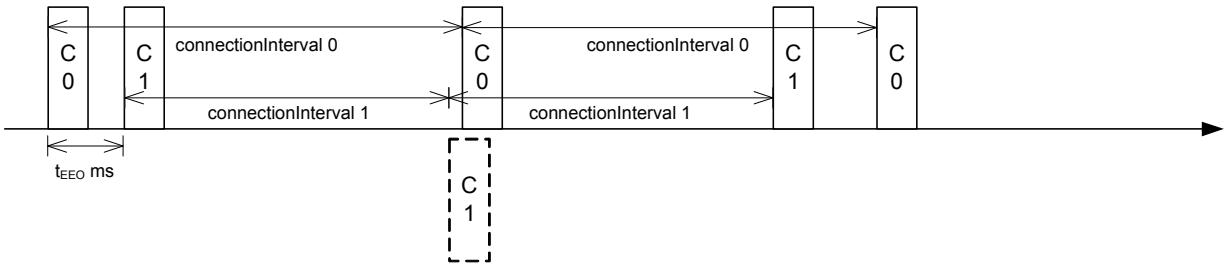


Figure 14 *Multi-link scheduling - one or more connections, unfactored intervals*

Value	Description	Range (µs)
t_{EEO}	Time between Radio Events (Event-to-Event Offset).	2000 to 2250
$t_{ScanReserved}$	Reserved time needed by the SoftDevice for each ScanWindow	1000

Table 25 *Multi-link central role timing ranges*

Figure 15 shows the maximum number of Central links possible at one time (8) with the minimum connection interval possible without having event collisions and dropped packets (20 ms). In this case, all available event time is used for the Central links.

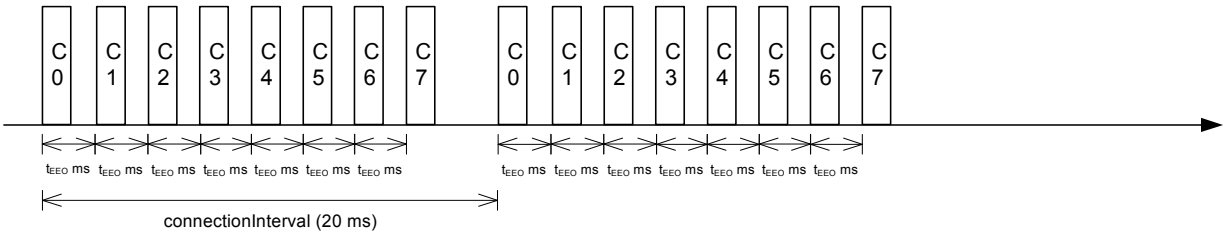


Figure 15 *Multi-link scheduling - max connections, min interval*

Figure 16 shows a scenario where the connInterval is longer than the minimum, and Central 2 and 4 have been disconnected or do not have events in this time period. It shows idle event time for each connection interval and the remaining Central connections maintain their timing offsets without the other links.

Figure 16 *Multi-link scheduling - max connections, interval > min*

11.2 Scanner timing

Figure 17 shows that when scanning for advertisers with no active connections, the scan interval and window can be any value within the *Bluetooth Core Specification*.

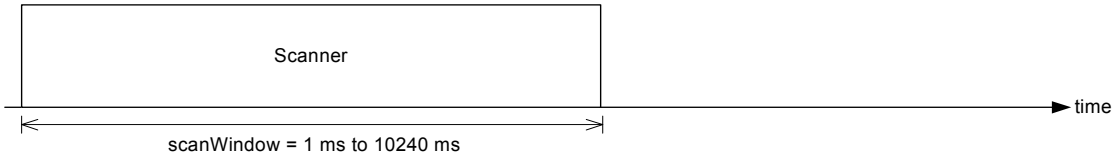


Figure 17 *Scanner timing - no active connections*

Figure 18 shows that when there is an active connection, the scanner or observer role will be started synchronously with the first connected Central link at a distance of 8(t_{EEO}) ms. With scanInterval equal to the connectionInterval and a scanWindow ≤ connectionInterval - (8*t_{EEO} + $t_{ScanReserved}$) ms, scanning will proceed without packet loss.

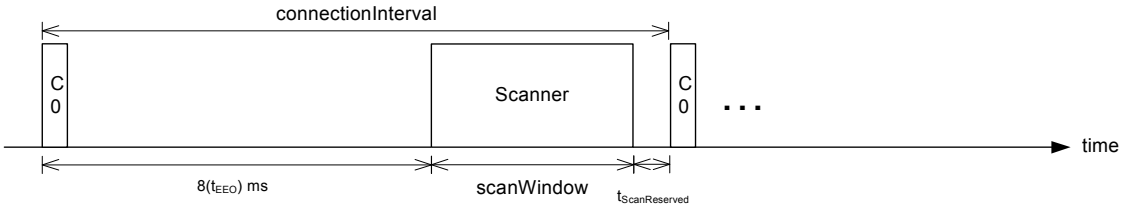


Figure 18 *Scanner timing - one connection*

Figure 19 shows a scanner with a long scanWindow which will cause some connection events to be dropped.

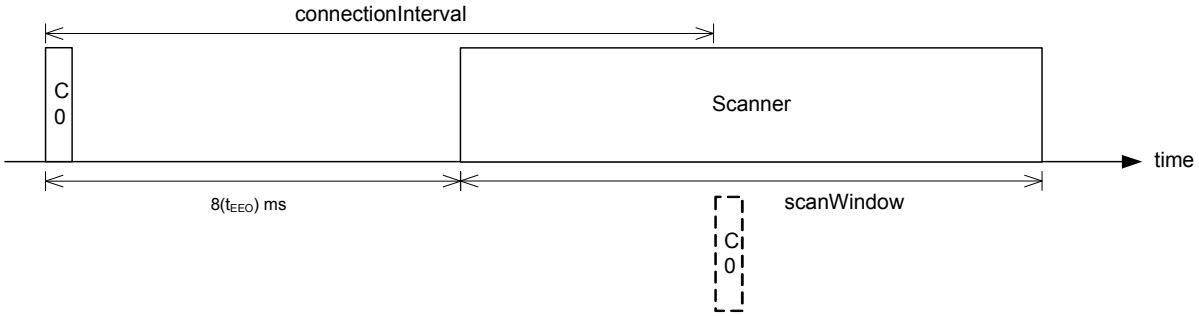


Figure 19 *Scanner timing - one connection, long window*

If all links have a short connection interval (20 ms) and the scanner is started, the scanner events will collide with Central link events causing packets on connections to be dropped as shown in ***Figure 20***.

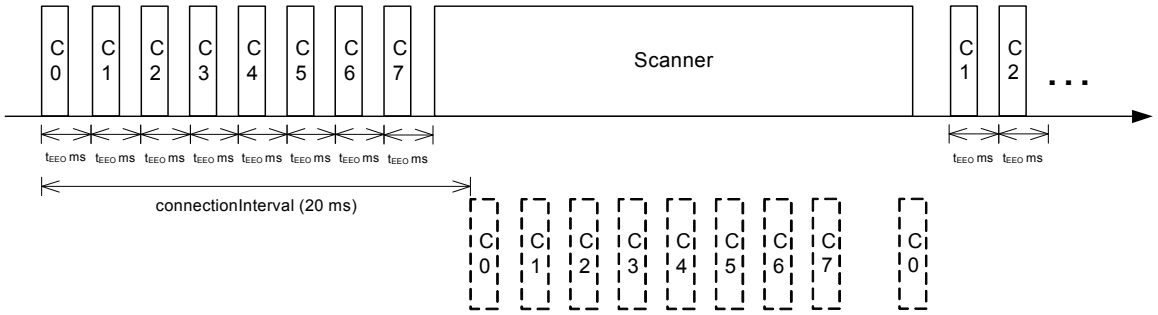


Figure 20 *Scanner timing - minimum connection interval*

11.3 Initiator timing

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 21***.

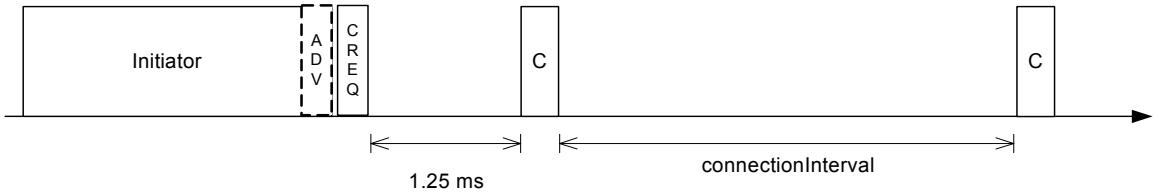


Figure 21 *Initiator - first connection*

When establishing a new connection with other connections already made, the initiator will start asynchronously to the connected link events and position the new Central connection's first event in a free slot between existing events. ***Figure 22*** illustrates this when all existing connections have the same connection interval and the initiator starts around the same time as the 7th Central connection (C6) event in the schedule. The new connection, C2, is positioned in the available slot between C1 and C3.

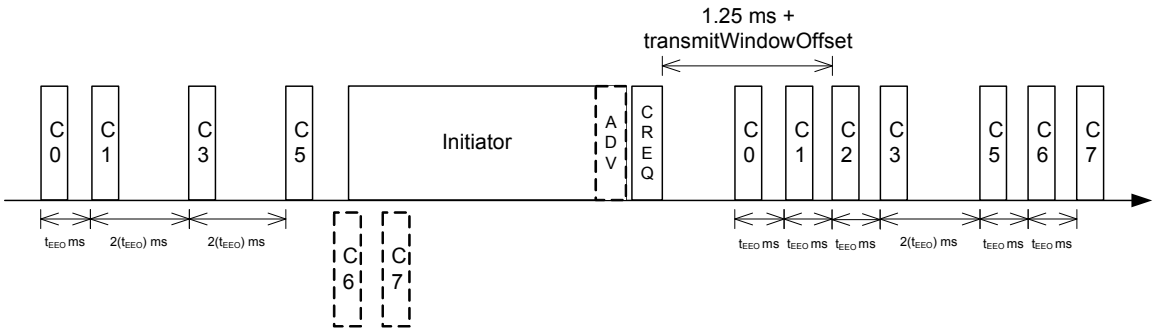


Figure 22 *Initiator - one or more connections*

When establishing connections to newly discovered devices, the scanner may be used for discovery followed by the initiator. In ***Figure 23***, the initiator is started directly after discovering a new device to connect as fast as possible to that device. The result is some connection events being dropped while the initiator runs. Central events scheduled in the transmit window offset will not be dropped (C3). In this case the 5th peer connection schedule is available (C4), and is allocated for the new connection.

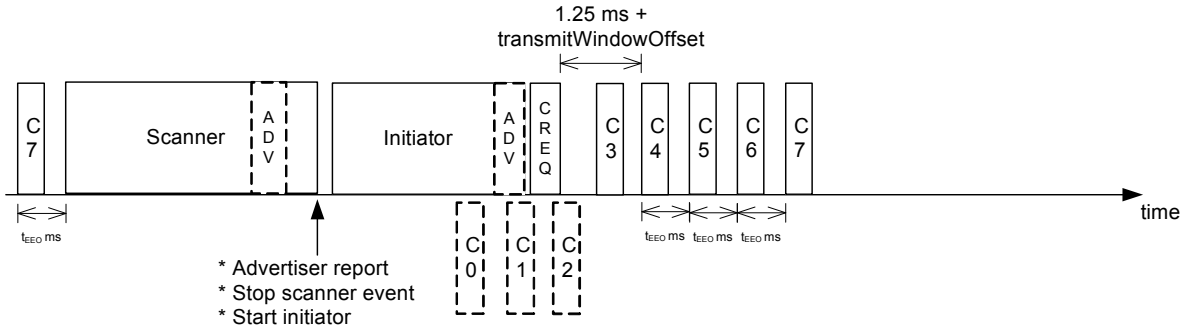


Figure 23 *Initiator - fast connection*

Note: It is not currently possible to schedule the initiator synchronously with connection events.

11.4 Suggested intervals and windows

The distance between each Central link needed to send and receive one full length BLE packet before another event starts, is t_{EEO}. Therefore eight link events can complete in maximum 8 * t_{EEO}, which is 18.0 ms (see ***Table 25*** on page 38).

The minimum connection interval recommended for eight connections is 20 ms. 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 as in ***Figure 20*** on page 41.

It is recommended that all connections have intervals that have a common factor. This common factor should be 20 ms or more. In the case of using 20 ms as the common factor, all connections would have an interval of 20 ms or a multiple of 20 ms like 40 ms, 60 ms, 80 ms, etc.

If short connections intervals are not essential to the application and there is a need to have a scanner and/or initiator running at the same time as connections (an initiator will have to be started to establish new connections), then it is possible to avoid dropping packets on any connection by having a connection interval larger than 18.0 ms plus the scanWindow plus $t_{ScanReserved}$. In this case, eight connections and a scanner/initiator window can complete within each connection interval.

As an example, setting the connection interval to 50 ms will allow eight connection events and a scanner/initiator 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 is:

1. The minimum Central connection intervals should be ≥ 8 * t_{EEO} + scanWindow + $t_{ScanReserved}$.
2. All Central connections should have connection intervals that have a common factor. This common factor should be 20 ms or more. For example [50 ms, 100 ms, 150 ms, 200 ms…] or [75 ms, 150 ms, 225 ms] etc.
3. Scanner, Observer, and Initiator roles should have intervals which can be factored by the smallest connection interval and the window should be ≤ connectionInterval – 8 * t_{EEO} – $t_{ScanReserved}$.

If the application configures connection intervals that are less than 20 ms, or connection intervals that do not have a common factor, or scan windows larger than recommended, the application should tolerate dropped packets by setting the supervision timeout for connections long enough to avoid loss of connection when packets are dropped due to collisions between connection events or between connection events and Scanner/Observer/Initiator events.

If roles/activities collide, their scheduling is determined by a priority system. If role A needs the radio at a time that overlaps with role B, and role A has higher priority, role A will get the event. Role B will be blocked from the event and will lose the event.

The different roles have different priorities at different times, dependent upon their state. Highest priority is given to connections that are about to time out. Thereafter comes connection creation and setup and connection parameter update. Scanning and normal connection events come as third priority.

As an example, if a connection is close to its supervision timeout it will block all other roles and get the events it requests. In this case all other roles will be blocked if they overlap with the connection event, and they will lose their events.

12 Processor availability and interrupt latency

This chapter documents key SoftDevice performance parameters for processor availability and interrupt latency.

12.1 Interrupt latency due to SoC framework

Latency, additional to ARM® Cortex™-M0 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. Additional latency is incurred due to interrupt processing and forwarding performed by the Master Boot Record (MBR). The maximum application interrupt latency is dependent on protocol stack activity as described in ***Section 12.2 "Processor availability"*** on page 45.

Interrupt	CPU cycles	Latency at 16 MHz
Open peripheral interrupt	49	3.1 µs
Blocked or restricted peripheral interrupt (only forwarded when SoftDevice disabled)	67	4.2 µs
Application SVC interrupt	43	2.68 µs

Table 26 *Additional latency due to SoftDevice and MBR processing*

See ***Table 21*** on page 35 for open, blocked, and restricted peripherals.

12.2 Processor availability

Appendix A on page 54 describes interrupt management in SoftDevices and is required knowledge for understanding this section.

The SoftDevice protocol stack runs in the LowerStack and UpperStack interrupts. These protocol stack interrupts determine the processor availability and latencies for the interrupts/priorities available to the application - App(H), App(L), and main.

LowerStack processing will determine the processor availability and interrupt latency for App(H) (and all lower priorities), while LowerStack, App(H), and UpperStack processing together will determine the processor availability for App(L) and main context. ***Figure 24*** illustrates UpperStack activity (API calls) and LowerStack activity (Protocol events) and the time reserved/not reserved for those interrupts.

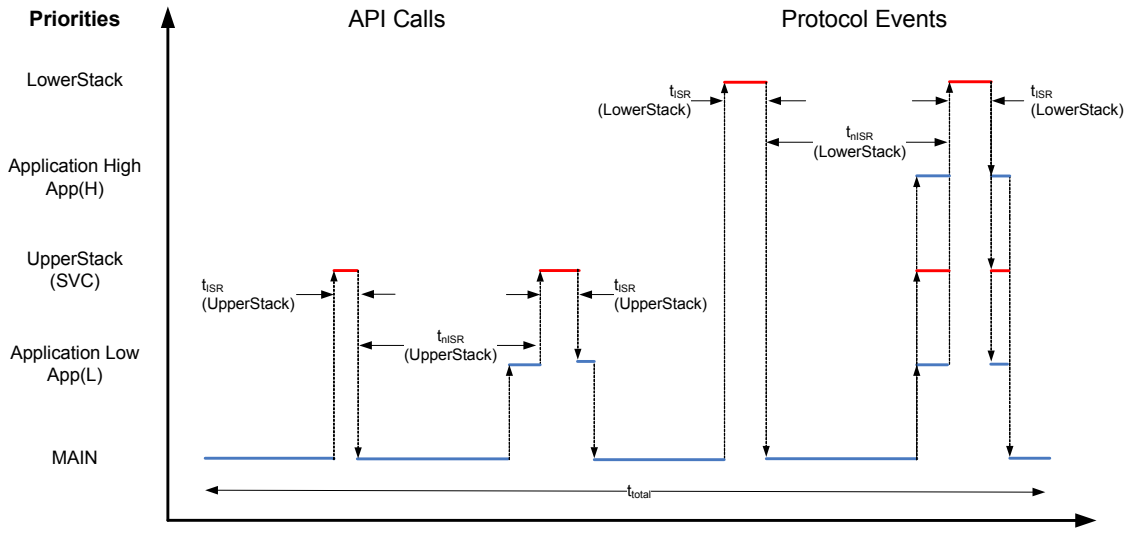


Figure 24 *UpperStack and LowerStack activity*

Table 27 describes the terms used for interrupt latency timings.

Parameter	Description
t_{ISR} (LowerStack)	Interrupt processing time in LowerStack. This is the interrupt latency for App(H) (and lower priorities).
t_{nISR} (LowerStack)	Time between LowerStack interrupts. This is the time available to run for App(H) (and lower priorities).
t_{ISR} (UpperStack)	Interrupt processing time in UpperStack. This is the interrupt latency for App(L) and processing latency for main context.
t_{nISR} (UpperStack)	Time between UpperStack interrupts. This is the time available to run for App(L) and main context.

Table 27 *SoftDevice interrupt latency definitions*

12.3 BLE central performance

This section describes the interrupt latency and processor availability for the BLE central stack.

The interrupt latency and processor availability interrupt latencies are dependent upon whether the SoftDevice uses CPU suspend[1] during radio activity or not. For previous S120 SoftDevices (S120 1.x series), CPU Suspend was always used. For current S120 SoftDevice versions (S120 2.x), CPU suspend is by default not enabled, but may optionally be enabled for compatibility with older versions of nRF51 chips. See your S120 SoftDevice release documentation for details. This document describes interrupt latency and CPU availability when CPU Suspend is not used.

12.3.1 Scanning interrupt latency

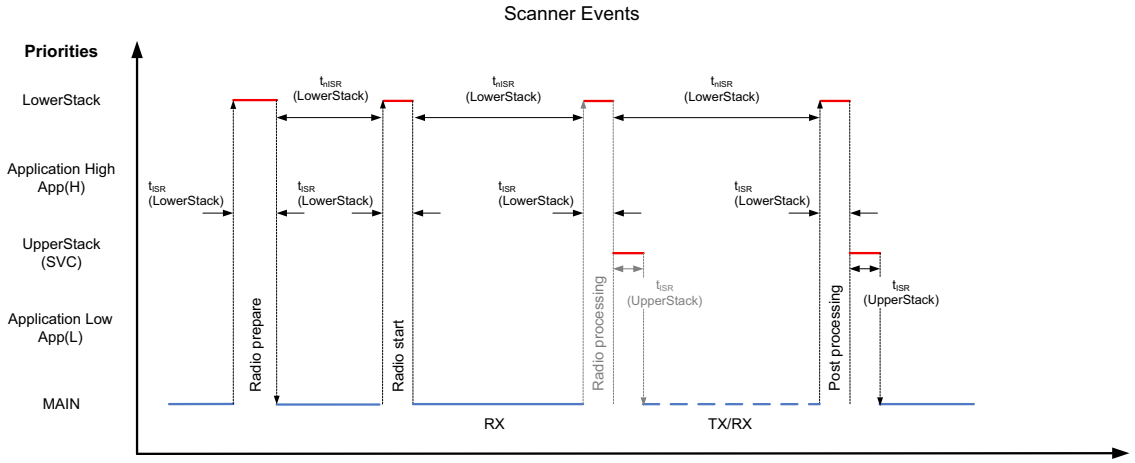


Figure 25 *Scanning*

For scanning, the pattern of LowerStack activity is as follows: There is first Radio prepare, followed by Radio start, which starts the actual scanning. During scanning, there will be zero or more instances of Radio processing, depending upon whether the 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 UpperStack processing. Finally, scanning ends with Post processing and some UpperStack activity.

Parameter	Description	Min.	Typ.	Max.
$t_{ISR(LowerStack),RadioPrepare}$	Interrupt latency preparing the radio for scanning.			140 µs
$t_{ISR(LowerStack),RadioStart}$	Interrupt latency starting the scan.			100 µs
$t_{ISR(LowerStack),RadioProcessing}$	Processing after sending/receiving packet.			200 µs
$t_{ISR(LowerStack),PostProcessing}$	Interrupt latency at the end of a scanner event.			680 µs
$t_{nISR(LowerStack)}$	Distance between interrupts during scanning.	30 µs		Scan Window
$t_{ISR(UpperStack)}$	UpperStack interrupt at the end of a scanner event.			0.1 ms

Table 28 *Interrupt latency for passive scanning*

1. CPU Suspend: During BLE protocol events, LowerStack interrupts are extended by a CPU Suspend state during radio activity to improve link integrity. This means LowerStack interrupts will block application and UpperStack processing during a Radio Activity for a time proportional to the number of packets transferred during the Radio activity period.

12.3.2 Initiating interrupt latency

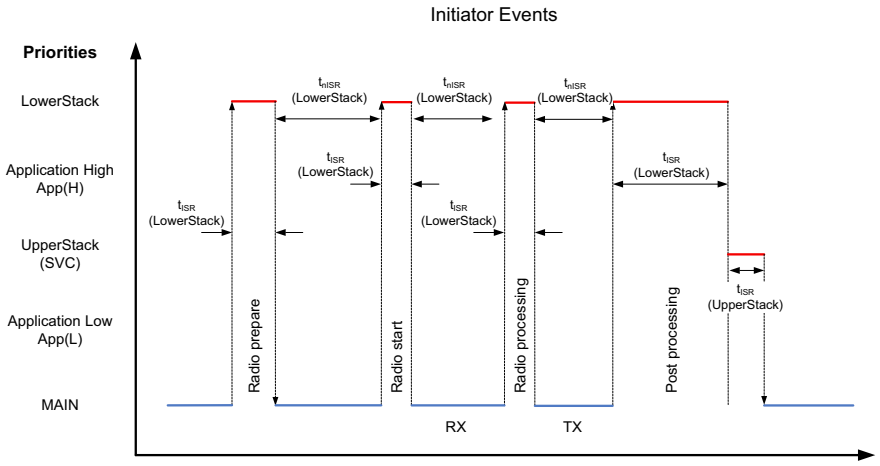


Figure 26 *Initiating*

For initiating, the pattern of LowerStack activity is as follows: There is first Radio prepare, followed by Radio start, which starts the actual initiating.

Upon receiving a connectable advertising packet, there will be Radio processing, which may result in sending a connect request. After having sent the connect request, initiating ends with Post processing and some UpperStack activity.

Parameter	Description	Min.	Typ.	Max.
$t_{ISR(LowerStack),RadioPrepare}$	Interrupt latency preparing the radio for scanning.			140 µs
$t_{ISR(LowerStack),RadioStart}$	Interrupt latency starting the scan.			100 µs
$t_{ISR(LowerStack),RadioProcessing}$	Interrupt latency after receiving ADV packets			200 µs
$t_{ISR(LowerStack),PostProcessing}$	Interrupt latency at the end of an initiator event.			680 µs
$t_{nISR(LowerStack)}$	Distance between interrupts during scanning.	30 µs		Scan Window
$t_{ISR(UpperStack)}$	UpperStack interrupt.			0.1 ms

Table 29 *Initiating interrupt*

12.3.3 Connection Event interrupt latency

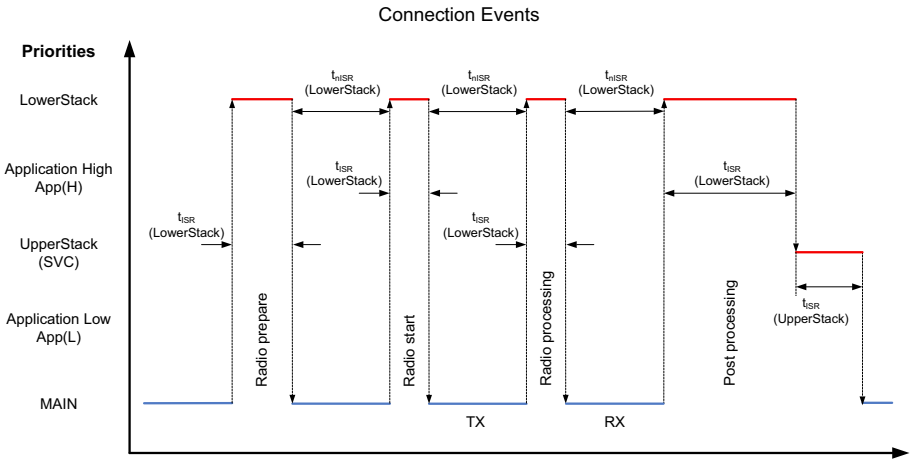


Figure 27 *Connection events*

In a connection event, the LowerStack activity is as follows: First there is Radio prepare and then Radio start, which starts the actual connection event (transmission). When the transmission is finished, there is a Radio processing including a switch to reception. When the reception is finished, the event ends with Post processing.

After the LowerStack Post processing, the UpperStack processes any received packets with data, executes GATT, ATT or SMP operations and generates events to the application as required. The UpperStack interrupt is therefore highly variable based on the stack operations executed. Interrupt latency during connections are outlined in ***Table 30***.

Parameter	Description	Min.	Typ.	Max.
$t_{ISR(LowerStack),RadioPrepare}$	Interrupt latency preparing the radio for connection event.			130 µs
$t_{ISR(LowerStack),RadioStart}$	Interrupt latency starting the connection event.			130 µs
$t_{ISR(LowerStack),RadioProcessing}$	Interrupt latency after sending packet.			150 µs
$t_{ISR(LowerStack),PostProcessing}$	Interrupt latency at the end of an connection event.			750 µs
$t_{nISR(LowerStack)}$	Distance between connection event interrupts.	30 µs		1400 µs
$t_{ISR(UpperStack)}$	UpperStack interrupt processing.			2 ms

Table 30 *Interrupt latency when connected*

12.3.4 Connection event CPU availability

Table 31 shows the CPU capacity available for an application with one, four, or eight connections. The available CPU capacity is given for different connection intervals for both idle connections (no data being transferred) and for busy connections (data being transferred in both directions in every connection event).

Number of connections	Connection interval	% CPU capacity available	
		Data transfer	Idle
1	7.5 ms	91%	92%
	20 ms	96%	97%
	100 ms	99%	99%
	150 ms	99%	99%
	1 s	>99%	>99%
4	7.5 ms	71%	72%
	20 ms	86%	87%
	100 ms	97%	97%
	150 ms	98%	98%
	1 s	>99%	>99%
8	7.5 ms	61%	62%
	20 ms	67%	71%
	100 ms	94%	94%
	150 ms	96%	96%
	1 s	>99%	>99%

Table 31 *CPU capacity available for the application, for an application with one, four, or eight connections.*

12.4 Performance with Flash memory API

The LowerStack interrupt is also used by the Flash memory API processing. Therefore use of these APIs may affect CPU availability and interrupt latencies for all lower priorities. The effects of this are dependent upon the application and the use case.

13 BLE data throughput

The maximum data throughput limits in ***Table 32*** apply to encrypted packet transfers. To achieve maximum data throughput, the application must exchange data at a rate that matches on-air packet transmissions and use the maximum data payload per packet.

The S120 SoftDevice limits packet transmission and reception to 1 packet each per connection event. All numbers displayed below are per connection.

Protocol	Role	Method	Number of connected slaves	Interval (ms)	Maximum data throughput
GATT	Client	Receive Notification	1 - 8 1 - 8	20 50	8 kbps 3.2 kbps
		Send Write command	1 - 8 1 - 8	20 50	8 kbps 3.2 kbps
		Send Write request	1 - 8 1 - 8	20 50	4 kbps 1.6 kbps
		Simultaneous receive Notification and send Write command	1 1 - 8 1 - 8	7.5 20 50	21.3 kbps (each direction) 8 kbps (each direction) 3.2 kbps (each direction)
GATT	Server	Send Notification	1 - 8 1 - 8	20 50	8 kbps 3.2 kbps
		Receive Write command	1 - 8 1 - 8	20 50	8 kbps 3.2 kbps
		Receive Write request	1 - 8 1 - 8	20 50	4 kbps 1.6 kbps
		Simultaneous send Notification and receive Write command	1 1 - 8 1 - 8	7.5 20 50	21.3 kbps (each direction) 8 kbps (each direction) 3.2 kbps (each direction)

Table 32 *Central side L2CAP and GATT maximum data throughput*

Note: 1 kbps = 1000 bits per second

14 BLE power profiles

This chapter provides power profiles for MCU activity during *Bluetooth* low energy Radio Events implemented in the SoftDevice. These profiles give a detailed overview of the stages of a Radio Event, the approximate timing of stages within the event, and how to calculate the peak current at each stage using data from the product specification. The LowerStack CPU profile (including CPU activity and CPU suspend) during the event is shown separately. These profiles are based on events with empty packets.

14.1 Connection event

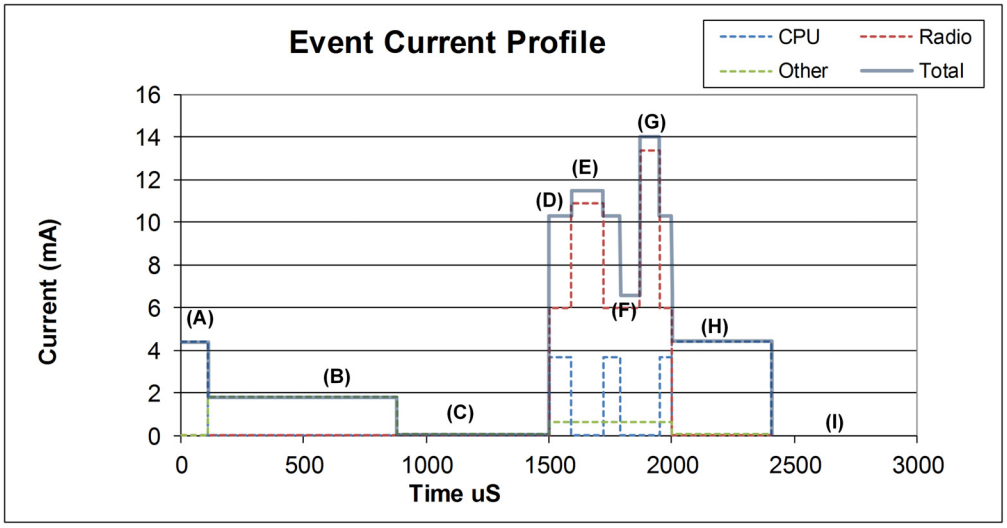


Figure 28 *Connection event*

Stage	Description	Current Calculations[1]
(A)	Preprocessing	$I_{ON} + I_{RTC} + I_{X32k} + I_{CPU,Flash}$
(B)	Standby + XO ramp	$I_{ON} + I_{RTC} + I_{X32k} + I_{START,X16M}$
(C)	Standby	$I_{ON} + I_{RTC} + I_{X32k} + I_{X16M}$
(D)	Radio Start	$I_{ON} + I_{RTC} + I_{X32k} + I_{X16M} + \int(I_{START,TX})$
(E)	Radio TX	$I_{ON} + I_{RTC} + I_{X32k} + I_{X16M} + I_{TX,0dBM}$
(F)	Radio turn-around	$I_{ON} + I_{RTC} + I_{X32k} + I_{X16M} + \int(I_{START,RX})$
(G)	Radio RX	$I_{ON} + I_{RTC} + I_{X32k} + I_{X16M} + I_{RX}$
(H)	Post-processing	$I_{ON} + I_{RTC} + I_{X32k} + I_{CPU,Flash}$
(I)	Idle - connected	$I_{ON} + I_{RTC} + I_{X32k}$

1. See the corresponding product specification for the symbol values.

Table 33 *Advertising event*

15 SoftDevice identification and revision scheme

The SoftDevices will be identified by the SoftDevice part code, a qualified chip part code (for example, nRF51822), and a version string.

For revisions of the SoftDevice that are production qualified, the version string consists of major, minor, and revision numbers only, as described in ***Table 34***.

For revisions of the SoftDevice that are not production qualified, a build number and a test qualification level (alpha/beta) are appended to the version string.

For example: s110_nrf51822_1.2.3-4.alpha, where major = 1, minor = 2, revision = 3, build number = 4 and test qualification level is alpha. Additional SoftDevice revision examples are given in ***Table 35***.

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

Table 34 *Revision scheme*

Sequence number	Description
s110_nrf51822_1.2.3-1.alpha	Revision 1.2.3, first build, qualified at alpha level
s110_nrf51822_1.2.3-2.alpha	Revision 1.2.3, second build, qualified at alpha level
s110_nrf51822_1.2.3-5.beta	Revision 1.2.3, fifth build, qualified at beta level
s110_nrf51822_1.2.3	Revision 1.2.3, qualified at production level

Table 35 *SoftDevice revision examples*

The test qualification levels are outlined in ***Table 36.***

Qualification	Description
Alpha	Development release suitable for prototype application development. Hardware integration testing is not complete. Known issues may not be fixed between alpha releases. Incomplete and subject to change.
Beta	Development release suitable for application development. In addition to alpha qualification: Hardware integration testing is complete. Stable, but may not be feature complete and may contain known issues. Protocol implementations are tested for conformance and interoperability.
Production	Qualified release suitable for product integration. In addition to beta qualification: Hardware integration tested over supported range of operating conditions. Stable and complete with no known issues. Protocol implementations conform to standards.

Table 36 *Test qualification levels*

15.1 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.

15.2 Notification of SoftDevice revision updates

When new versions of a SoftDevice become available or the qualification status of a given revision of a SoftDevice is changed, product update notifications will be automatically forwarded, by email, to all users who have a profile configured to receive notifications from the Nordic Semiconductor website.

The SoftDevice will be updated with additional features and/or fixed issues if needed. Supported production versions of the SoftDevice will remain available after updates, so products do not need requalification on release of updates if the previous version is sufficiently feature complete for your product.

Appendix A SoftDevice architecture

Figure 1 is a block diagram of the nRF51 series software architecture including the standard ARM® CMSIS interface for nRF51 hardware, profile and application code, application specific peripheral drivers, and a firmware module identified as a SoftDevice.

A SoftDevice is precompiled and linked binary software implementing a wireless protocol. While it is software, application developers have minimal compile-time dependence on its features. The unique hardware and software supported framework, in which it executes, provides run-time isolation and determinism in its behavior. These characteristics make the interface comparable to a hardware peripheral abstraction with a functional, programmatic interface.

The SoftDevice Application Program Interface (API) is available to applications as a high-level programming language interface, for example, a C header file.

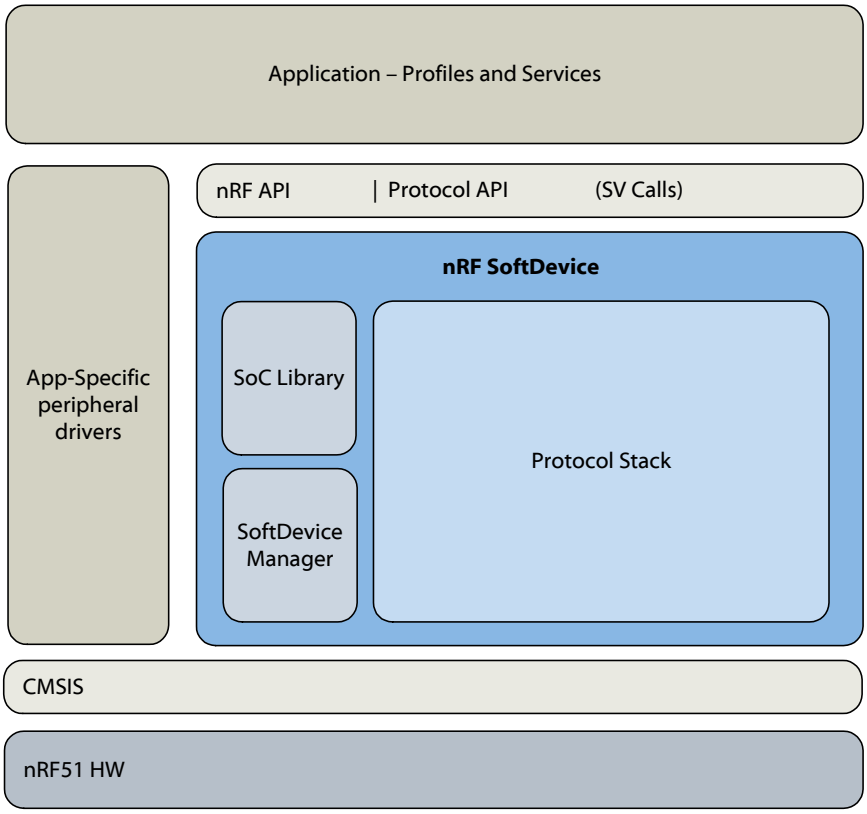


Figure 1 *Software architecture block diagram*

A SoftDevice consists of three main components:

1. SoC Library - API for shared hardware resource management (application coexistence).
2. SoftDevice manager - SoftDevice management API (enabling/disabling the SoftDevice, etc.).
3. Protocol stack - Implementation of protocol stack and API.

When the SoftDevice is disabled, only the SoftDevice Manager API is available for the application. For more information about enabling/disabling the SoftDevice, see the Softdevice enable and disable section on page 62.

SoC library

The SoC library provides functions for accessing shared hardware resources. The features of this library will vary between implementations of SoftDevices so detailed descriptions of the SoC library API are made available with the Software Development Kits (SDK) specific to each SoftDevice. The following is a summary of common components in the library.

Component	Description
NVIC	Wrapper functions for the CMSIS NVIC functions provided by ARM®. **Note:** To ensure reliable usage of the SoftDevice you must use the wrapper functions when the SoftDevice is enabled.
MUTEX	Disabling interrupts shall not be done while the SoftDevice is enabled. Mutex functions have been implemented to provide safe regions.
RAND	Random number generator - hardware sharing between SoftDevice and application.
POWER	Power management - Functions for power management.
CLOCK	Clock management – Functions for managing clock sources.
PPI	Safe PPI access to dedicated Application PPI channels.
PWR_MNG	Power management support (not a full implementation) for the application.

SoftDevice Manager

The SoftDevice Manager (SDM) API implements functions for controlling the state of the SoftDevice enabled/disabled. When enabled, the SDM configures low frequency clock (LFCLK) source, interrupt management and the embedded protocol stack.

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

Protocol stack

The major component in each SoftDevice is a wireless protocol stack providing abstract control of the RF transceiver features for wireless applications. For example, fully qualified *Bluetooth* low energy and ANT™ protocols layers may be implemented in a SoftDevice to provide application developers with an out-of-the-box solution for applications using standard 2.4 GHz protocols.

Application Program Interface (API)

In addition, to a Protocol API enabling wireless applications, there is a nRF API that supports both the SoftDevice manager and the SoC library. The nRF API is consistent across SoftDevices in the nRF51 range of ANT™ and *Bluetooth* products for code compatibility.

The SoftDevice API is implemented using thread-safe Supervisor Calls (SVC). All application interaction with the stack and libraries is asynchronous and event driven. From the application this looks like regular functions, but no compiling or linking is required. All SVC interface functions will be provided through header files for the SDM, SoC Library, and protocol(s).

SV calls are conceptually software triggered interrupts with a procedure call standard for parameter passing and return values. Each API call generates an interrupt allowing single-thread API context and SoftDevice function locations to be independent from the application perspective at compile-time. SoftDevice API functions can only be called from lower interrupt priority when compared to the SVC priority. See the Exception (interrupt) management with a SoftDevice section ***on page 58***.

Memory isolation and run-time protection

SoftDevice program memory, data memory and peripherals can be sandboxed[1] to prevent SoftDevice program corruption by the application ensuring robust and predictable performance. Sandboxing is enabled by writing the start address of the application program memory to UICR.CLENR0.

Program memory and RAM are divided into two regions using registers. Region 0 is occupied by the SoftDevice while Region 1 is available to the application.

Code regions are defined when programming a SoftDevice by setting a register defining program code length. RAM regions are defined at run-time when the SoftDevice is enabled. See ***Figure 2*** for an overview of regions.

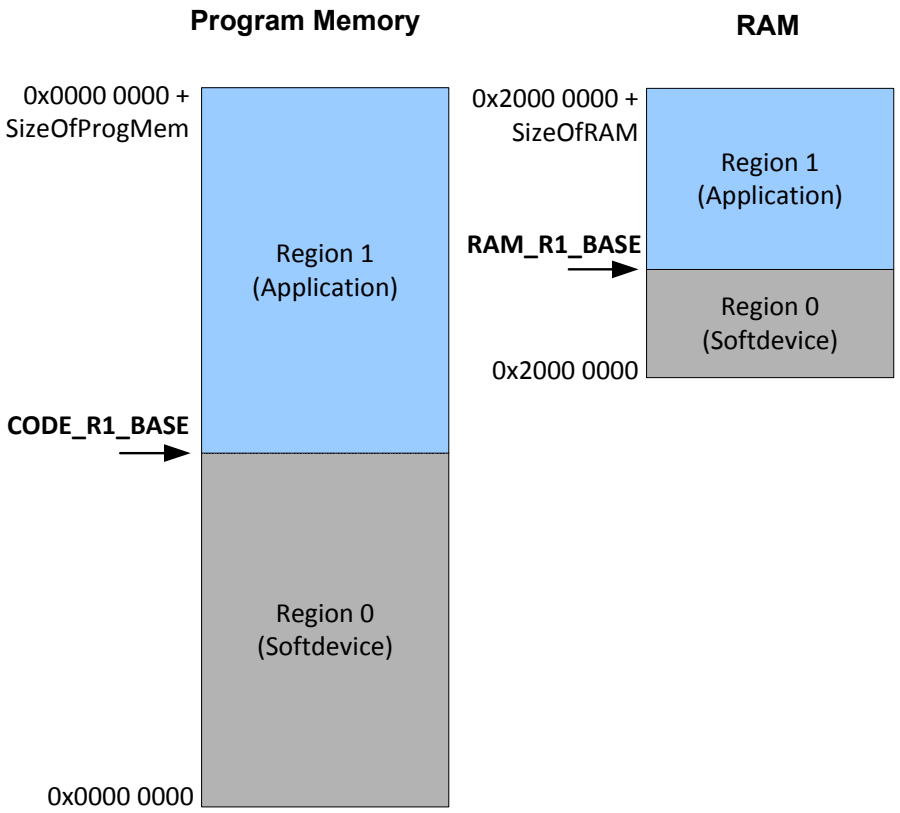


Figure 2 *Memory region designation*

The SoftDevice uses a fixed amount of flash (program) memory and a variable amount of RAM depending on its state. The flash and RAM usage is specified by size (kilobytes or bytes) and the CODE_R1_BASE and RAM_R1_BASE addresses which are the usable base addresses of Application code and RAM respectively. Application code must be located between CODE_R1_BASE and SizeOfProgMem while the Application RAM must be allocated between RAM_R1_BASE and the top of RAM, excluding the allocation for the call stack and heap.

Example Application program code address range:

```
CODE_R1_BASE ≤ Program ≤ SizeOfProgMem
```

1. A sandbox is a set of access rules for memory imposed on the user.

Example Application RAM address range assuming call stack and heap location as shown in:

```
RAM_R1_BASE ≤ RAM ≤ (0x2000 0000 + SizeOfRAM) - (Call Stack + Heap)
```

Sandboxing protects region 0 memory. Region 0 program memory cannot be written or erased at runtime[2]. Region 0 RAM cannot be written to by an application at runtime. Violation of these rules, for example an attempt to write to the protected Region 0 memory, will result in a system Hard Fault as defined in the ARM® architecture. There are debugger restrictions applied to these regions which are outlined in the *"Memory Protection Unit (MPU)"* chapter in the *nRF51 Reference Manual* that do not affect execution.

When the SoftDevice is disabled the whole of RAM, with the exception of a few bytes, is available to the application. In the context of an enabled SoftDevice however, lower address space of RAM will be "consumed" by the SoftDevice and be marked as write protected.

It is important to note that when the SoftDevice is disabled, the RAM previously used by the application will not be restored. In practice, the application will in many cases want to specify its RAM region from the protected memory length until the end of RAM. This is to make application development easy without having to think about what data to put where.

Note:

- The call stack is conventionally located by the initial value of Main Stack Pointer (MSP) at the top address of RAM.
- By default RAM1 block is OFF in System ON-mode. If the MSP initial value defined in the application vector table is in the RAM1 block, the RAM block will be enabled before the application reset vector is executed.
- Do not change the value of MSP dynamically (i.e. never set the MSP register directly).
- RAM located in the SoftDevice's region will be scrambled once the SoftDevice is enabled.
- The RAM scrambled by the SoftDevice will not be recovered on SoftDevice disable.

Call stack

The call stack is defined by the application. The main stack pointer (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 used 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.

In configurations without an OS, the main stack grows down and is shared with the nRF51 SoftDevice. The Cortex-M0 has no hardware for detecting stack overflow, and the application is responsible for leaving enough space both for the application itself and the nRF51 SoftDevice stack requirements.

It is customary, but not required, to let the stack run downwards from the upper limit of RAM Region 1.

2. An exception is replacing the SoftDevice using MBR API functions.

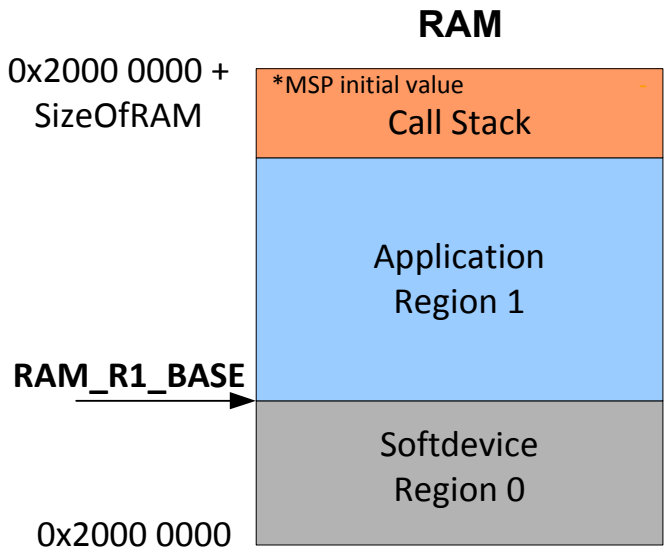


Figure 3 *Call stack location example*

With each release of a nRF51 SoftDevice its maximum (worst case) call stack requirement is specified, see the SoftDevice specification for more information. The SoftDevice uses the call stack when LowerStack or UpperStack events occur. These events are asynchronous to the application so the application programmer must reserve call stack for the application in addition to the call stack requirement for the SoftDevice.

Heap

At this time there is no heap required by nRF51 SoftDevices. The application is free to allocate and use a heap without disrupting the function of a SoftDevice.

Peripheral run-time protection

To prevent the application from accidentally disrupting the protocol stack in any way, the application sandbox also protects SoftDevice peripherals. Protected peripheral registers are readable by the application. As with program and data memory protection, an attempt to perform a write to a protected peripheral will result in a Hard Fault. Note that peripherals are only protected while the SoftDevice is enabled, otherwise they are available to the application. See the SoftDevice specification for an overview of the peripherals that are restricted by the SoftDevice.

Exception (interrupt) management with a SoftDevice

To implement Service Call (SVC) APIs and ensure that embedded protocol real-time requirements are met independent of application processing, the SoftDevice implements an exception model for execution as shown in ***Figure 4*** on page 59. Care must be taken when selecting the correct interrupt priority for application events according to the guidelines that follow. The NVIC API to the SoC Library supports safe configuration of interrupt priority from the application.

The Cortex-M0 processor has four configurable interrupt priorities ranging from 0 to 3 (with 0 being highest priority). On reset, all interrupts are configured with the highest priority (0).

The highest priority (LowerStack) is reserved by the SoftDevice to service real-time protocol timing requirements and thus must remain unused by the application programmer. The SoftDevice also reserves priority 2 (UpperStack (SVC) priority). This priority is used by higher level, deferrable, SoftDevice tasks and the API functions executed as SVC interrupts (see Interface section ***on page 55***).

The application provides two configurable priorities, App(H) and App(L), in addition to the background level - main.

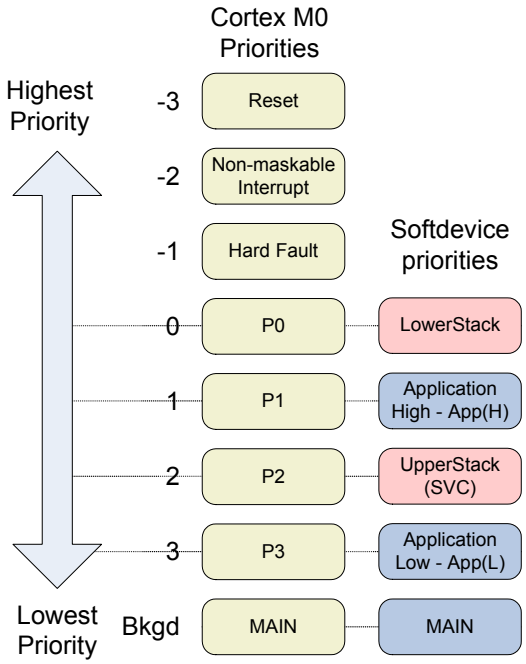


Figure 4 *Exception model*

As seen from the figure, App(H) is located between the two priorities reserved by the SoftDevice. This enables a low-latency application interrupt in order to support fast sensor interfaces. The App(H) will only experience latency from interrupts in the LowerStack priority, while App(L) can experience latency from LowerStack, App(H) and UpperStack context interrupts.

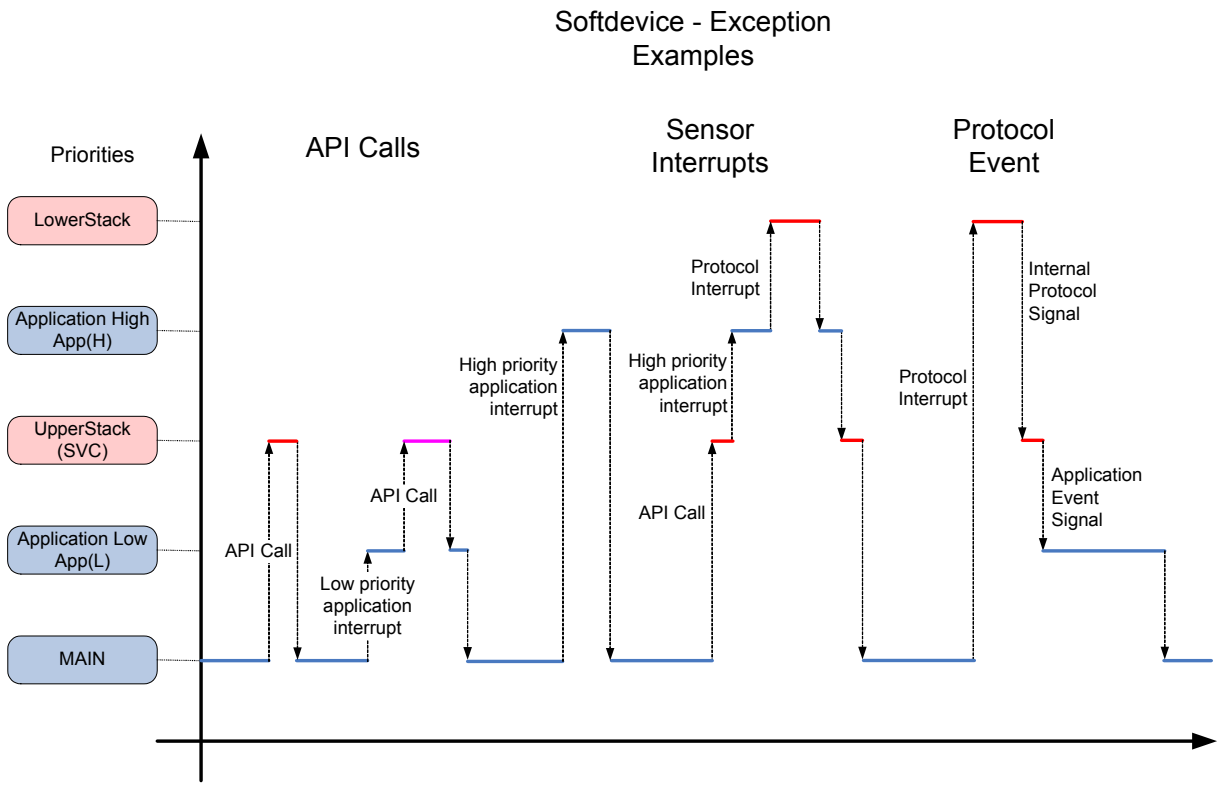


Figure 5 *SoftDevice exception examples*

Interrupt forwarding to the application

At the lowest level, the SoftDevice Manager receives all interrupts regardless of enabled state. When the SoftDevice is enabled, some interrupt numbers are reserved for use by the protocol stack implemented in the SoftDevice and any handler defined by the application will not receive these interrupts. The reserved interrupts directly correspond to the hardware resource usage of the SoftDevice which can be found in the corresponding SoftDevice Specification. For example, if a SoftDevice (or embedded protocol stack) requires the exclusive use of a peripheral "TIMER0", that peripheral's interrupt handler can be implemented in the application, but will not be executed while the SoftDevice is enabled.

All interrupts corresponding to hardware peripherals not used by the SoftDevice are forwarded directly to the application defined interrupt handler. For the SoftDevice Manager to locate the application interrupt vectors, the application must define its interrupt vector table at the bottom of code Region 1, see ***Figure 6*** on page 61. The use of a bootloader introduces some exceptions to this, see chapter ***Chapter 9 "Master Boot Record and Bootloader"*** on page 30. In a majority of toolchains, the base address of the application code is positioned after the top address of the SoftDevice. Then, the code can be developed as a standard ARM® Cortex™-M0 application project with the compiler tool creating the interrupt vector table as normal.

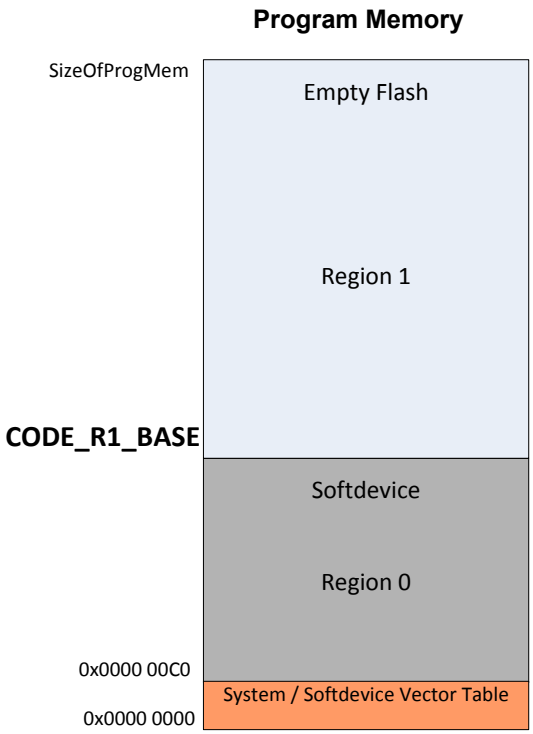


Figure 6 *System and application interrupt vector tables*

SVC interrupt is handled by SoftDevice manager and the SVC number inspected. If equal or greater than 0x10, the interrupt is processed by the SoftDevice. Values below 0x10 cause the SVC to be forwarded to the application. This allows the application to make use of a range of SVC numbers for its own purpose, for example, for an RTOS.

Note: While the Cortex™-M0 allows each interrupt to be assigned to an IRQ level 0 to 3, the priorities of the interrupts reserved by the SoftDevice cannot be changed. This includes the SVC interrupt. Handlers running at Application High level have neither access to SoftDevice functions nor to application specific SVCs or RTOS functions running at Application Low level.

If the SoftDevice is not enabled, all interrupts are immediately forwarded to the application specified handler. The exception to this is that SVC interrupts with an SVC number above or equal to 0x10 are not forwarded.

Events - SoftDevice to application

Software triggered interrupts in reserved IRQ slots are used to signal events from SoftDevice to application. For details on this technique and how to implement handling of these events, refer to the Software Development Kit (SDK) for your device.

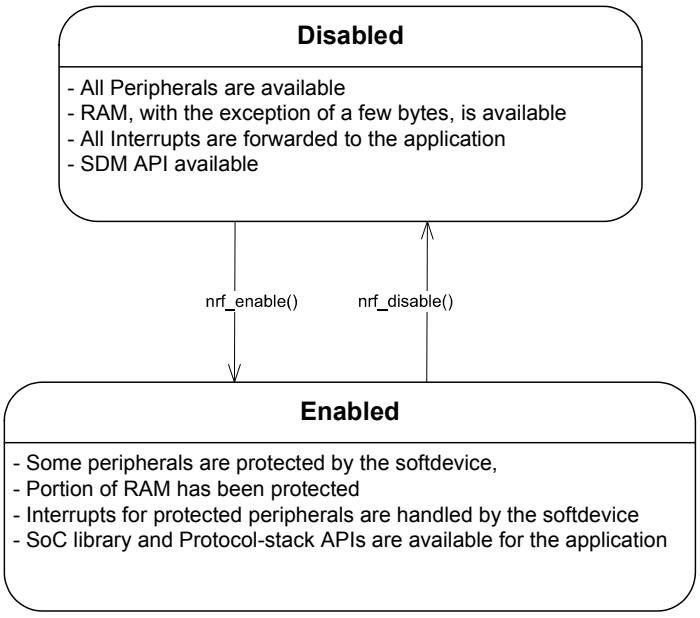
SoftDevice enable and disable

Before enabling the SoftDevice, you cannot use any capabilities of the SoftDevice. This extends to the use of the SoC library and protocol stack functions. All of the chip's resources are freely available to the application, with some exceptions:

- SVC numbers 0x10 to 0xFF are reserved.
- SoftDevice program memory is reserved.
- A few bytes of RAM are reserved.

Once the SoftDevice has been enabled, more restrictions apply:

- Some RAM will be reserved.
- Some peripherals will be reserved.
- Some of the peripherals that are reserved will have a SoC library interface.
- Interrupts will not arrive in the application for reserved peripherals.
- 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.
- Maximum interrupt latency will be determined by the SoftDevice.



Power management

While the SoftDevice is disabled, the application must implement power management at the highest level. After a SoftDevice is enabled, the POWER peripheral will be protected. This means that all interactions with the POWER peripheral must happen through the SoC Library Power API. This API provides an interface for turning on/off peripherals and checking the power status of peripherals that are not protected by the SoftDevice. The application will also have the ability to set the other registers in the peripheral and put the chip in System OFF.

Error handling

All SoftDevice API functions return an error code on success and failure.

Hard Faults are triggered if an application attempts to access memory contrary to the sandbox rules or peripheral configurations at runtime.

An assertion mechanism through a registered callback can indicate fatal failures in the SoftDevice to the application.