M2351 TrustZone[®] Program Development

Application Note for 32-bit NuMicro[®] Family

Document Information

Abstract	Introduce TrustZone [®] programing including how to partition security attribution and how to develop program in the Keil [®] MDK environment, and show sample code.
Apply to	NuMicro [®] M2351 series

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Table of Contents

1	OVERVIEW
2	TRUSTZONE® INTRODUCTION52.1 Memory Map Security Attribution Configuration62.1.1IDAU62.1.2SAU72.2 Secure and Non-secure State Switch92.2.1Non-secure Code Calls Secure Function92.2.2Secure Code Calls Non-secure Function92.2.3Non-secure Security Attribution Check10
3	KEIL® MDK DEVELOPMENT ENVIRONMENT113.1 Security Attribution Configuration113.1.1Memory Map123.1.2Flash123.1.3SRAM133.1.4Peripheral143.1.5Peripheral Interrupt143.2 Secure and Non-secure Project Setting153.2.1Secure Code153.2.2Non-secure Code21
	3.2.2.Non-secure Code 21 3.3 Secure and Non-secure State Switch 23 3.3.1Execute from Secure Code to Non-secure Code 23 3.3.2Non-secure Code Calls Secure Function 25 3.3.3Secure Code Calls Non-secure Function 29
4	SAMPLE CODE.314.1 Security Attribution Configuration.324.1.1Memory Map.324.1.2Flash334.1.3SRAM.334.1.4Peripheral344.1.5Peripheral Interrupt344.2 Secure and Non-secure State Switch344.2.1Execute from Secure Code to Non-secure Code34
	4.2.2Non-secure Code Calls Secure Function

	4.2.4Non-secure Security Attribution Check	37
5	CONCLUSION	.39

1 Overview

In the IoT (Internet of Things) application, devices not only can communicate with each other through the Internet, but can be attacked through the Internet. The security is an important topic to protect device and information. The Arm[®] TrustZone[®] technology partitions hardware into Secure and Non-secure world (or trusted and un-trusted world). Users can implement their own authentication method additionally. With the TrustZone[®] technology and software method, microcontrollers (MCUs) can provide secure application and make it flexible to design. This document will introduce the TrustZone[®] technology including how to partition security attribution and how to develop program in the Keil[®] MDK environment, and show sample code.

2 TrustZone[®] Introduction

The Arm[®] TrustZone[®] technology partitions the system into two regions. One is Secure world and another is Non-secure world. The available microcontroller resources including Flash, SRAM, peripherals and peripheral interrupts security attribution can also be configured to Secure or Non-secure. After planning the security attribution of these resources, Non-secure world can only access Non-secure memories and resources, while Secure world can access all memories and resources, including Secure and Non-secure resources. Important data that needs protection can be placed and processed in the Secure world safely. Access of Secure world is limited. The protected data would not be stolen or broken by anyone or anyone untrusted.

	Secure View	Non-secure View		Secure View	Non-secure View	
0xFFFFFFFF	System	System	1/	Non-secure SCB		
0xF0000000	System control	ntrol System control		Non-secure NVIC		
0xE0000000	5 5		Non-Secure SysTick			
				Debug	Debug	
	External Peripheral	External Peripheral		SAU		
				Secure SCB	Non-secure SCB Non-secure NVIC	
0xA0000000				Secure NVIC		
	External SRAM	External SRAM		Secure SysTick	Non-Secure SysTick	
				ITM/DWT/FPB	ITM/DWT/FPB	
0x60000000						
0x50000000	Non-secure Peripheral	Non-secure Peripheral				
0x40000000	Secure Peripheral			Secu	re	
0x30000000	Non-secure SRAM	Non-secure SRAM	ecure SRAM		secure	
0x20000000	Secure SRAM			Not a	vailable	
0x10000000	Non-secure Flash	Non-secure Flash		Othe		
0x00000000	Secure Flash					
Address Memory Map						

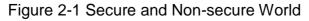


Figure 2-1 shows the configuration of resource security attribution. The memory map, Flash, SRAM and peripherals are partitioned into Secure or Non-secure attribute. When the code is executed in Secure memory, the system is called Secure code. The Secure code can access all resources including Secure and Non-secure. When the code is executed in the Non-secure memory, the system is called Non-secure code. The Non-secure code can only access Non-secure resource. Beside the defined access authority, Secure code can provide Non-secure callable function to allow more authority for Non-secure code access.

2.1 Memory Map Security Attribution Configuration

In the Arm[®] TrustZone[®] technology, the memory map security attribution partition can be configured by IDAU (Implementation Defined Attribution Unit) and SAU (Security Attribution Unit). The security attribution can be configured as Secure(S), Non-secure(NS) and Non-secure callable(NSC). Non-secure callable entry function should be placed in Non-secure callable memory if Secure code provides Non-secure callable function. NuMicro[®] M2351 series define a fixed memory map security attribution by IDAU. User still can change security configuration partition by SAU. The result of security attribution is the higher security setting between IDAU and SAU. The priority of security attribution is Secure(S) has the highest secure priority, then Non-secure callable(NSC) has lower secure priority and Non-secure(NS) has the lowest secure priority. The undefined region is Secure(S) by default.

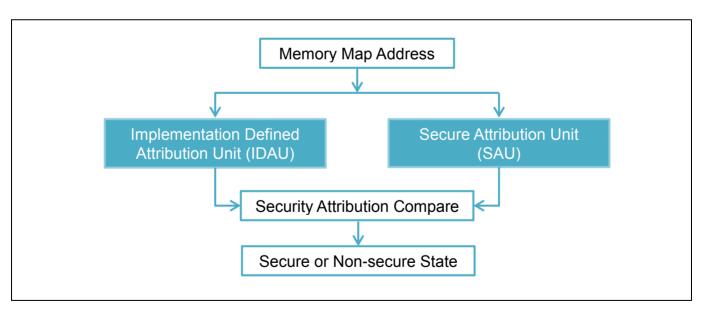


Figure 2-2 Memory Map Address Security Attribution Configuration

2.1.1 IDAU

Figure 2-3 shows the NuMicro[®] M2351 series memory map security attribution partition defined by IDAU. The memory map address bit 28 is used to define the security attribution. If the memory map address bit 28 is 0, it is Secure(S). In Flash and SRAM region, it is Non-

secure callable (NSC). If the memory map address bit 28 is 1, it is Non-secure(NS). The first 2 Kbytes of Flash are fixed to Secure(S). The system related register does not partition into certain security attribution. They are determined by current system state.



Figure 2-3 IDAU Defined Memory Map Address Security Attribution

2.1.2 SAU

User can change security configuration partition by SAU. Table 2-1 lists the SAU control registers. Figure 2-4 shows how to configure security attribution by SAU. All memory map can be configured to Secure(S) by setting SAU_CTRL.ALLNS=0 or be configured to Non-

secure(NS) by setting SAU_CTRL.ALLNS=1. To configure security attribution in detail, user can set the SAU_CTL, SAU_RNR, SAU_RBAR and SAU_RLAR register. Set SAU_CTL.ENABLE=1 to enable SAU, set SAU_RNR (which region to set), SAU_RBAR (with start address), SAU_RLAR (with end address) and SAU_RLAR.NSC. Set SAU_RLAR.NSC=0 to configure specify memory map region security attribution to Non-secure(NS) and set SAU_RLAR.NSC=1 to configure as Non-secure callable (NSC). The security attribution of the regions which do not specified by SAU is Secure(S).

SAU Register	Address	Description		
SAU_CTRL	0xE000EDD0	SAU control register.		
SAU_TYPE 0xE000EDD4		The number of SAU setting region, read only.		
SAU_RNR 0xE000EDD8		SAU setting region.		
SAU_RBAR	0xE000EDDC	SAU setting start address.		
SAU_RLAR	0xE000EDE0	SAU setting end address and attribution.		

Table 2-1 SAU Control Register

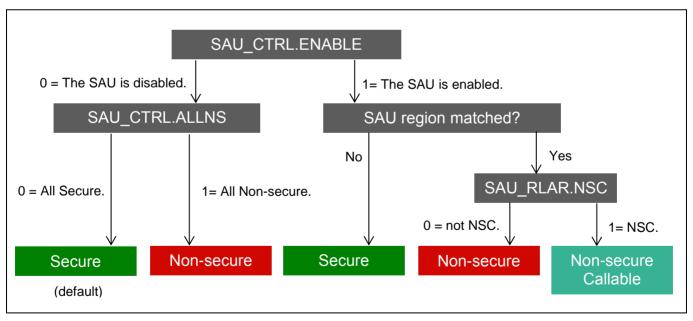


Figure 2-4 SAU Security Attribution Configuration

2.2 Secure and Non-secure State Switch

Functions in Secure code and Non-secure code can call each other. Secure code can call Non-secure function directly but Non-secure code cannot call Secure function directly. If Secure code allows Non-secure code to call a Secure function, it is a Non-secure callable function. Secure code should place related Non-secure callable entry function in Non-secure callable region. Non-secure code call Non-secure callable entry function then can call secure function.

2.2.1 Non-secure Code Calls Secure Function

When Non-secure code calls Secure function, it calls Non-secure callable entry function at first. The first instruction of Non-secure callable entry function is SG instruction. It is the entry point that allows the code state switches from Non-secure state to Secure state. Non-secure callable function is end with BXNS instruction and returns to Non-secure code.

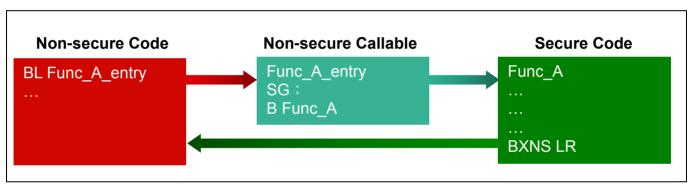


Figure 2-5 Non-secure Code Calls Secure Function

BL: Branch with link instruction

Func_A_entry: Non-secure callable entry function

- SG: Secure gateway instruction
- B: Branch instruction
- Func_A: Secure function
- **BXNS:** Branch with exchange to Non-secure state instruction

2.2.2 Secure Code Calls Non-secure Function

Secure code uses a BLXNS instruction to call Non-secure function. Before switching secure state to Non-secure state, return address and processor information are pushed into the Secure stack, while the return address on Link Register (LR) is set to a special value FNC_RETURN. Non-secure function completes with branch to FNC_RETURN address. The actual return address unstacks to Secure stack and returns to Secure state.

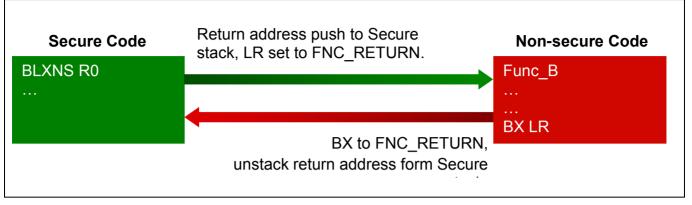


Figure 2-6 Secure Code Calls Non-secure Function

BLXNS: Branch with link and exchange to Non-secure state instruction

R0: Address of Non-secure function with LSB is 0

FNC_RETURN: 0xFEFFFFF

Func_B: Non-secure function

BX: Branch with exchange instruction

2.2.3 Non-secure Security Attribution Check

Secure code provides Non-secure callable function for Non-secure code to call secure function. It also provides parameters and return values. Secure function can check the memory security by cmse_check_adress_range intrinsic before reading or modifying any data to prevent the important data from being stolen or broken. To use cmse_check_adress_range intrinsic, set the flag parameter as CMSE_NONSECURE, and the address range to check is from p to p+1. If the checked addresses are all in Secure memory, it returns the address p. Otherwise, it returns NULL. Another intrinsic cmse_check_pointed_object can also be used to check address security attribution.

```
void* cmse_check_adress_range(void *p, size_t size, int flags);
void* cmse check pointed object(void *p, int flags);
```

3 Keil[®] MDK Development Environment

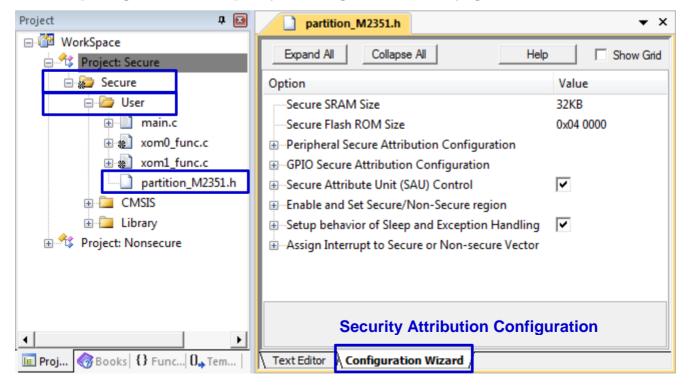
This section describes how to develop NuMicro[®] M2351 series TrustZone[®] program with Keil[®] MDK. The development environment has to support Cortex[®]-M23 core and Armv8-M architecture. The download and debug tool is Nuvoton Nu-Link Debugger.

The resource security attributions need to be planed first before developing TrustZone[®] program. User should determine which resources are planned for Secure code and which resources are planned for Non-secure code. The Secure and Non-secure code are two projects. Flash and SRAM address need to be specified to compile and download code correctly. If Secure code provides Non-secure callable function for Non-secure code, Secure project needs to create a Non-secure callable function library. If Non-secure code wants to use Non-secure callable function, Non-secure project has to add Non-secure callable function library. The state switched between Secure and Non-secure state can be observed when executing the code.

3.1 Security Attribution Configuration

Security attribution is configured in Secure code. The partition_M2351.h file provides a configuration wizard interface for user to configure the resources security attribution easily. The security attribution configuration includes memory map, Flash, SRAM, peripherals and peripheral interrupts. The following section will introduce how to configure security attribution through partition_M2351.h file configuration wizard interface.

- 1. Click [Secure] to expand the folder. The [partition_M2351.h] file is in [User] folder.
- 2. Click [Configuration Wizard] to open Configuration Wizard page.



3.1.1 Memory Map

Memory map security attribution is set by SAU. For example, plan the address 0x3F000-0x3F7FF for Non-secure callable function and set the security attribution as Secure and Nonsecure callable.

- 1. In the [Enable and Set Secure/Non-secure Region], select [SAU Region 3].
- 2. Specify the start address by setting [Start Address] to [0x00003F000].
- 3. Specify the end address by setting [End Address] to [0x00003F7FF].
- 4. In the [Region is], select [Secure, Non-secure Callable] from the pull-down menu.

partition_M2351.h	▼ ×
Expand All Collapse All Help	Show Grid
Option	Value
Secure Attribute Unit (SAU) Control	✓
Enable SAU	
All Memory Attribute When SAU is disabled	All Memory is Secure
Enable and Set Secure/Non-Secure region	
i∎SAU Region 0	Memory Map Security
SAU Region 1	Attribution Configuration
i∰SAU Region 2	
⊡SAU Region 3	▼
Start Address	0x0003 F000
End Address	0x0003 F7FF
Region is	Secure, Non-Secure Callable
SAU Region 3	
Setup SAU Region 3	
Text Editor Configuration Wizard	

3.1.2 Flash

Flash security attribution is set by the register NSCBA (Non-secure base address register, address 0x00200800). NSCBA sets the start address of Non-secure region in Flash and its read/write is through FMC. User can read register SCU_FNSADDR (Flash Non-secure address register, address 0x4002F028) to get current NSCBA setting. For example, set NSCBA value as 0x40000.

• In the [Secure Flash ROM Size], set Non-secure region start address as [0x040000].

partition_M2351.h			▼ ×
Expand All Collapse All Help	□ s	how Grid	
Option	Value		
Secure SRAM Size	32KB		
Secure Flash ROM Size	0x04 0000	Flash Security Attribution	
Peripheral Secure Attribution Configuration		Configuration	
GPIO Secure Attribution Configuration			
Secure Attribute Unit (SAU) Control	✓		
Enable and Set Secure/Non-Secure region			-
Secure Flash ROM Size			
Text Editor Configuration Wizard			

3.1.3 SRAM

SRAM security attribution is set by the register SCU_SRAMNSSET (SRAM secure attribution set register, address 0x4002F024). For example, set the first 32 Kbytes SRAM as Secure (address 0x2000000-0x20007FFF) and set the following 64 Kbytes SRAM as Non-secure (address 0x30008000-0x30017FFF).

• In the [Secure SRAM Size], select [32KB] from the pull-down menu.

partition_M2351.h	▼	×
Expand All Collapse All Help	Show Grid	
Option	Value	
Secure SRAM Size	32KB 💌	
 Secure Flash ROM Size Peripheral Secure Attribution Configuration GPIO Secure Attribution Configuration Secure Attribute Unit (SAU) Control Enable and Set Secure/Non-Secure region Setup behavior of Sleep and Exception Handling Assign Interrupt to Secure or Non-secure Vector 	0 KB 8KB 16KB 24KB 32KB 40KB 40KB 48KB 56KB 64KB 72KB 80KB	
Secure SRAM Size	88KB 96KB	
\ Text Editor \ Configuration Wizard \		

3.1.4 Peripheral

Peripheral security attributions are set by the register SCU_PNSSET0-SCU_PNSSET6 (Peripheral secure attribution set register 0-6, address 0x4002F000-0x4002F018) and SCU_IONSSET (I/O secure attribution set register, address 0x4002F01C). For example, set the UART1 security attribution as Non-secure.

 In the [Peripheral Secure Attribution Configuration] → [UART1], select [Non-secure] from the pull-down menu.

partition_M2351.h		• ×
Expand All Collapse All	Help Show Grid	
Option	Value	
-Peripheral Secure Attribution Configuration		
i⊒UART		✓ × Peripheral Security Attribution Configuration
UART0	Secure	
- UART1	Non-Secure Peripheral Security	
UART2	Attribution Configuration	
UART1	Non-Secure	
Text Editor Configuration Wizard		

3.1.5 Peripheral Interrupt

Peripheral interrupt security attributions are set by the register NVIC_ITNS0-NVIC_ITNS3 (Interrupt Target Non-secure Register 0-3, address 0xE000_E380-0xE000_E38C). For example, set UART1 interrupt security attribution as Non-secure.

In the [Assign Interrupt to Secure or Non-secure Vector] \rightarrow [UART1] select [Non-Secure] from the pull-down menu.

partition_M2351.h			▼ ×	
Expand All Collapse All Help	Show Grid			
Option	Value			
⊨-Assign Interrupt to Secure or Non-secure Vector			^	
RTC	Secure	Peripheral Interrupt		
UARTO	Secure	Security Attribution		
UART1	Non-Secure 💌	Configuration		
	Secure	5	-	
UART1	Non-Secure			
Text Editor Configuration Wizard				

3.2 Secure and Non-secure Project Setting

This section describes Secure and Non-secure project setting. Flash and SRAM address has to be set according to the security attribution configuration. Secure project needs to create Non-secure callable function library if Secure code provides Non-secure callable function. Non-secure project needs to add Non-secure callable function library if Non-secure code wants to use Non-secure callable function.

3.2.1 Secure Code

Device setting:

- 1. Open Secure project in the Keil[®] MDK environment.
- 2. Click [Project] on the menu bar and click [Options for Target] to open the configuration window.
- 3. Under the [Device] page, select Nuvoton \rightarrow NuMicro Family \rightarrow M2351 \rightarrow M2351KIAAEES.

Options for Target 'Secure'	×
Device Target Output Listing User C/C++ (AC6)	Asm Linker Debug Utilities
Software Packs	-
Vendor: Nuvoton	Software Pack
Device: M2351KIAAEES	Pack: Nuvoton.NuMicro_DFP.1.1.2
Toolset: ARM	URL: <u>http://www.nuvoton.com/hq/enu/Document</u>
Search:	
📄 🔍 Nuvoton 🔺 The N	uMicro M2351 series 32-bit microcontrollers
in SD Family	
🖃 😤 NuMicro Family	
i	
🕀 🏤 🔂 Generic	
⊕ 🍄 M0518	
⊕ 🏤 M0519	
Bevice setting	
i	
M2351KIAAEES	
▲	-
ОК	Cancel Defaults Help

Software model setting:

- 1. In the [Options for Target] window, click [Target] page.
- 2. In the [Code Generation] section, select [Software Model] as [Secure Mode].

Very Secure Secu								
Device Target Output Listing User C/C++ (AC6) Asm Linker Debug Utilities Software model settin								
Nuvoton M2351KIAAEES								
	No. 1 (10) 12	0		Generation -				
	<u>X</u> tal (MHz): 12		ARM	Compiler:	Use default	compiler version	on 💌	
Operating system: None		-	Softw	are Model:	Secure Mod	le	-	
System Viewer File:					Non-Secure Secure Mod			
M2351_v1.svd			🔽 U	se MicroLIB		Big Endian		
, Use Custom File								
Read/Only Memory Areas —			Read/	Write Memo	ry Areas ——			
default off-chip Start	Size	Startup	default	off-chip	Start	Size	Nolnit	
ROM1:		0		RAM1:				
ROM2:		0		RAM2:				
ROM3:		0		RAM3:				
on-chip				on-chip				
IROM1: 0x0	0x80000	œ		IRAM1:	x20000000	0x18000		

Flash, SRAM and Non-secure callable entry function location setting:

- 1. In the [Options for Target] window, click [Linker] page.
- In the [Scatter File] section, click [Edit] button to edit [secure.sct]. Set Secure Flash start address as 0x00000000 and size as 0x10000. Set Secure SRAM start address as 0x20000000 and size as 0x800. Locate Non-secure callable entry function in Veneer\$\$CMSE region. Set the Non-secure callable region start address is 0x3F000 and size is 0x800.

Secure code creates Non-secure callable function library:

• In the same [Linker] page, under the [Misc controls] section, create the output library nsclib_Secure.o by adding command [--import-cmse-lib-out ..\lib\nsclib_Secure.o].

The Secure code adds "cmse_nonsecure_entry" attribute for Non-secure callable function.

attribute__((cmse_nonsecure_entry))

AN0019

Options for Target 'Secure'	x
Device Target Output Listing User C/C++ (AC6) Asm Linker Debug Utilities	
□ Use Memory Layout from Target Dialog X/O Base: □ Make RW Sections Position Independent R/O Base: □ Make RO Sections Position Independent R/W Base □ Don't Search Standard Libraries disable Warnings:	
Flash, SRAM and Non-secure callable entry function location setting Scatter File Edit Secure code creates Non-secure callable function library	
Misc controls	
Linker control string	
OK Cancel Defaults Help	

secu	ire.sct		•	×
1				*
2	LR ROM 0x0 0x10000		- 6	
3	{			
4				Ξ
5	EXE_ROM +0			
6	{			
7	<pre>*.o(RESET, +First)</pre>			-
8	* (+RO)			
9	}	Flash and SRAM location setting		
10				
11	EXE_RAM 0x20000000 0x8000			
12	{			
13	*(+RW, +ZI)			
14	}			
15				
16	}			Ŧ
	III		•	

nuvoton

secure.sct		•	×
17 18 LR_NSC 0x3f000 0x800 19 { 20 NSC_ROM +0 21 { 22 * (Veneer\$\$CMSE) 23 } 24 } 25	Non-secure callable entry function location setting		* III

Debugger setting:

- 1. In the [Options for Target] window, click [Debug] to open [Debug] page.
- 2. Use [Nuvoton Nu-Link Debugger] as debugger.
- 3. Click [Settings] button to open [Debug] window.
- 4. Select [Chip Type] as [M2351] from the pull-down menu.

Options for Targe	t 'Secure'			X
Device Target Ou	tput Listing User	C/C++ (AC6) As	m Linker Debug	Utilities Debugger setting
C Use Simulator	with restrictions	Settings	C Use: Nuvoton N	u-Link Debugger 🔽 Settings
Limit Speed to	Debug			
✓ Load Applicati Initialization File:	Nu-Link Driver Version:	6633a	Chip Select	2351 - I Fite 1
Restore Debug (ICE Version:	6633	- Reset Options	Edit
Breakpoint Watch Wir Memory Dia	Device Family: Device ID:	Cortex-M 0x0BF11477	Connect: Norn Reset: Auto	nal 💌 idetect 💌 jewer
CPU DLL:	Port: Max Clock:	SW	Download Options	
Dialog DLL:	Supporting Forum		Cancel	ОК
	Mar	nage Component Vie	wer Description Files	
	(OK Can	cel Defaults	Help

Debug Secure and Non-secure code setting:

- 1. In the same [Debug] page, under the [Initialization File] section, click [Edit] button to edit [debug.ini]
- 2. Add command to load Non-secure image at the start of the debug session, to debug both Secure and Non-secure code.

Options for Target 'Secure'	×		
Device Target Output Listing User C/C++ (AC6) A	sm Linker Debug Utilities		
C Use Simulator with restrictions Settings	Use: Nuvoton Nu-Link Debugger Settings		
Limit Speed to Real-Time Debu	g Secure and Non-secure code setting		
✓ Load Application at Startup ✓ Run to main()	Load Application at Startup Run to main()		
Initialization File:	Initialization File:		
Edit	debug.ini Edit		
Restore Debug Session Settings	Restore Debug Session Settings		
Breakpoints Toolbox	Breakpoints Toolbox		
✓ Watch Windows & Performance Analyzer	✓ Watch Windows		
Memory Display Vistem Viewer	✓ Memory Display System Viewer		
CPU DLL: Parameter:	Driver DLL: Parameter:		
	SARMV8M.DLL -MPU		
Dialog DLL: Parameter:	Dialog DLL: Parameter:		
	TCM.DLL pV8MBL		
, ,	, , , , , , , , , , , , , , , , , , ,		
Manage Component Ma	ewer Description Files		
Manage Component vie	wer Description nies		
OK Car	ncel Defaults Help		

/		debu	g.ini	De	bug Secure and Non-secure code setting	•	, x
		1	load ⁹	%l incr	emental		
		2	g, ma:	in			
		3	load '	"\\	\\NonSecure\\Keil\\Objects\\NonSecure.axf"	incremental	no
		4					
 •	_		111				- P.

Download Secure and Non-secure code setting:

- 1. In the [Option for Target] window, click [Utilities] page.
- 2. In the [Configure Flash Menu Command] section [Init File] option.
- 3. Click [Edit] button to edit [nonsecure.ini] to download both Secure and Non-secure code.

V Options for Target 'Secure'
Device Target Output Listing User C/C++ (AC6) Asm Linker Debug Utilities
Configure Flash Menu Command Download Secure and Non-secure code setting
Use Debug Driver Settings 🔽 Update Target before Debugging
Init File: Nonsecure.ini
C Use External Tool for Flash Programming
Command:
Arguments:
Run Independent
Configure Image File Processing (FCARM):
Output File: Add Output File to Group:
CMSIS
Image Files Root Folder:
OK Cancel Defaults Help

	non:	secure.ini	Download Secure and Non-secure code setting	→ ×
	1			
	2	load	"/\\\NonSecure\\Keil\\Objects\\NonSecure.axf"	
	3			
1 • 1				

3.2.2 Non-secure Code

Software model setting:

- 1. Open Non-secure project in the Keil[®] MDK environment.
- 2. Click [Project] on the menu bar and click [Options for Target] to open the configuration window.
- 3. In the [Options for Target] window, click [Target] page.
- 4. In the [Code Generation] section, select [Software Model] as [Non-secure Mode].

Options for Target 'NonSecure'	×							
Device Target Output Listing User C/C++ (AC6) A								
Nuvoton M2351KIAAEES								
<u>X</u> tal (MHz): 12.0	ARM Compiler: Use default compiler version							
Operating system: None	Software Model: Non-Secure Mode							
System Viewer File:	Non-Secure Mode Secure Mode							
M2351_v1.svd	Use MicroLIB Big Endian							
Use Custom File								
Read/Only Memory Areas	Read/Write Memory Areas							
default off-chip Start Size Startup	default off-chip Start Size NoInit							
□ ROM1: □ C	□ RAM1: □ □							
□ ROM2: □ C	□ RAM2: □ □							
П ROM3: С С	RAM3:							
on-chip	on-chip							
IROM1: 0x0 0x80000 €	IRAM1: 0x20000000 0x18000 □							
□ IROM2: □ 0	□ IRAM2: □							
, ,	, ,							
OK Car	ncel Defaults Help							

Flash and SRAM location setting:

- 1. In the [Options for Target] window, click [Linker] page.
- 2. In the [Scatter File] section, click [Edit] button to edit [nonsecure.sct]. Set Non-secure code Flash start address as 0x10040000 and size as 0x10000. Set Non-secure SRAM start address as 0x30008000 and size as 0x10000.

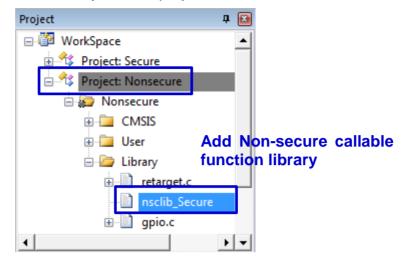
AN0019

Options for Target 'Nonsecure'	×
Device Target Output Listing User C/C++ (AC6) Asm Linker Debug Utilities Use Memory Layout from Target Dialog X/O Base:	
Flash and SRAM location setting	Edit
Misc controls	*
Linker control -library_type=microlibstrictscatter "nonsecure.sct" string	r T
OK Cancel Defaults	Help

<u>non</u>	secure.sct	•	×
1 2 3 4 5 6 7 8 9 10	<pre>LR_ROM 0x10040000 0x10000 { EXE_ROM +0 { *.o(RESET, +First) *(+RO) } </pre>	Flash and SRAM location setting	- III
10 11 12 13 14 15 16 17	EXE_RAM 0x30008000 0x10000 {	•	Ŧ

Add Non-secure callable function library:

Add [nsclib_Secure.o] which is created by Secure project to use Non-secure callable function.



3.3 Secure and Non-secure State Switch

Secure and Non-secure code can run after compiling and downloading Secure and Nonsecure project. The state switches between Secure and Non-secure state that can be observed by debug session. This section demonstrates how Secure code calls Non-secure function and Non-secure code calls Secure function by debug session.

3.3.1 Execute from Secure Code to Non-secure Code

Start Secure code debug session:

Click [Debug] on the menu bar and click [Start Debug Session].

😨 C:\M2351BSP\SampleCode\TrustZone\Template\Secure\KEIL\Secure.uvprojx - 猩ision						
<u>F</u> ile <u>E</u> dit <u>V</u> iew <u>P</u> roject Fl <u>a</u> sh	Deb	ug Pe <u>r</u> ipherals <u>T</u> ools <u>S</u>	VCS <u>W</u> indow	<u>H</u> elp		
D 💣 🖌 🗿 X 🖕 🖎	Q	Start/Stop <u>D</u> ebug Session	Ctrl+F5	/= //👷 🖄		
🛛 🔗 🕮 🕮 🥔 🧮 🙀 🛛 Secu	r RST	Reset CPU Start Secur	e code deb	g session		
Project 🛛 🗜 🔛	10,	Run	F5			
□ I WorkSpace	8	Stop				
H Project: Secure	$\overline{\{\cdot\}}$	Step	F11			
🗄 😤 Project: Nonsecure	$\overline{\{\}}^{\downarrow}$	Step O <u>v</u> er	F10			
	$\{ \}^{\!\!\!\!\!\!\!}$	Ste <u>p</u> Out	Ctrl+F11			
	7{}	Run to Cursor <u>L</u> ine	Ctrl+F10			

Secure code:

System executes Secure code (main.c) at first.

```
Secure code
     main.c
                                                                                 ▼ ×
   208
        int main(void)
                                                                                   ٨
   209 🖂 {
   210
             SYS UnlockReg();
   211
   212
             SYS Init();
   213
             /* UART is configured as debug port */
   214
   215
             DEBUG PORT Init();
           Ш
٠.
                                                                                P.
```

Add Non-secure code symbol:

Click [View] on the menu bar and click [Symbols Window] to open the configuration window. In [Nonsecure] project [main_ns.c] file, find the [main] function. Right click and select [Show code for 'main()'] to add Non-secure code symbol.

Symbols		д	×
Module / Name	Location	Туре	
Nonsecure		Application	
⊕ [™] [™] <types></types>			1
🖶 😤////Library/StdDriver/src/gpio.c		Module	
🗄 😤////Library/StdDriver/src/retarget.c		Module	
🗄 😤////Library/Device/Nuvoton/M2351/Source/ARM/startup_M2351.s		Module	
🖶 쓚////Library/Device/Nuvoton/M2351/Source/system_M2351.c		Module	
🖶 😤//Nonsecure/xom3_func.c		Module	
🕀 😤//Nonsecure/xom2_func.c		Module	1
🗄 🏤//Nonsecure/main_ns.c		Module	1
SysTick_Config	0x10040A20	unsigned int f(_
WVIC_SetPriority	0x10040860	void f(enum (IR	1
🕀 🖤 🐓 SysTick_Handler	0x10040A7C	void f()	1
🗈 🔍 🖗 NonSecure_LED_On	0x10040912	int f(unsigned i	1
NonSecure_LED_Off	0x100408E6	int f(unsigned i	1
🗄 🗝 🔶 LED_On	0x10040838	void f(unsigned	
Add Non-secure code symbol	0x10040810	void f(unsigned	1
main	0x10040B74	int f()	1
DEBUG_PORT_Init Show code for 'main()'	0x10040796	void f()	1
SysTick_Config Expand 'main' to Clipboard	0x10040A20	unsigned int f(1
NVIC_SetPriority Set Tracepoint at 'main()'	0x10040860	void f(enum (IR	1
• _fp_digits	0x10040CE8	function	

Non-secure code:

Then system can execute Non-secure code (main_ns.c).

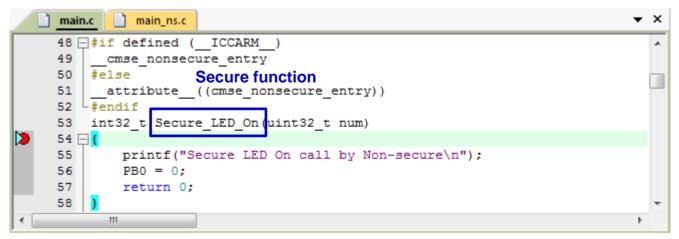
) main.	Mon-secure code	▼ ×
	96 🖂]/*	· · · · · ·
	97	Main function	
	98	*	
	99	int main(void)	
	100 📮	3] 🤆	
	101	<pre>DEBUG_PORT_Init();</pre>	
	102		
	103	<pre>printf("\n");</pre>	_
	104	printf("++\n");	
	105	<pre>printf(" Nonsecure is running \n");</pre>	
	106	printf("++\n");	
	107		
	108	Secure_func();	
	109		-
•			•

3.3.2 Non-secure Code Calls Secure Function

This section describes Non-secure code calls Secure function to show how Non-secure state switches to Secure state. When Non-secure code calls Non-secure callable function, it calls related Non-secure callable entry function in Non-secure callable region. The first instruction of Non-secure callable entry function is SG instruction. SG instruction is the entry point for Non-secure state switching to Secure state. Then Non-secure callable function can be called by Non-secure code.

If Non-secure code (main_ns.c) wants to call Non-secure callable function (Secure_LED_On) it calls \$Ven\$TT\$L\$Secure_LED_On at first.

Secure code:



Secure code:

	main.c main_ns.c	▼ ×
	48 = #if defined (ICCARM)	*
	49cmse_nonsecure_entry	
	50 #else	
	<pre>51attribute((cmse_nonsecure_entry))</pre>	
	52 L#endif	
	53 int32_t Secure_LED_On(pint32_t num)	
	55 printf("Secure LED On call by Non-secure\n");	
	56 PBO = 0;	
	57 return 0; Non-secure code calls Secure function	
	58 }	-
•	III	F.

I. Т

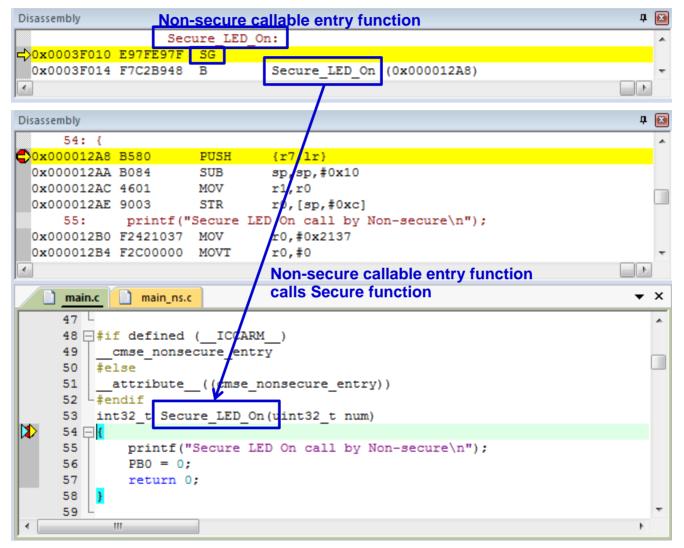
I.

Non-secure code:

Disassembly	L.		Ļ	
78:	Secure L	ED On(6u);		
Ox10040ABA 2006	MOVS	<u>∞0,#€</u>		_
0x10040ABC F000	F8B2 BL	<pre>\$Ven\$TT\$L\$\$Secure_LED_On (0x10040C24)</pre>		
79:	break;	1		Ŧ
•		/	•	
🗋 main.c 📄 <u>m</u>	ain_ns.c		-	×
	sTick_Handler	(void)		*
69 🖓 {				
	tic uint32_t	ticks;		
71	.	Non-secure code calls		
	tch(ticks++)	Non-secure callable entry function		
73 - {	case 0:			
75	LED on (7	(m) •		
76	break;	u),		
77	case 200			
78		ED On(5u);		
79	preak;			Ŧ
			F	
Disassembly			ņ	
	\$Ven\$TT\$L\$\$	Secure_LED_On:		*
<mark>⊏></mark> 0x10040C24 B403	PUSH	{r0,r1}		
0x10040C26 4801	LDR	r0,[pc,#4] ; @0x10040C2C		
0x10040C28 9001	STR	r0,[sp,#4]		
0x10040C2A BD01	POP	{r0,pc}		
0x10040C2C F011	DOO3 DCI.W	0xf0110003 ; ? Undefined		Ŧ
•			•	

\$Ven\$TT\$L\$Secure_LED_On calls Non-secure callable entry function (Secure_LED_On) in Non-secure callable region. System can switch from Secure state to Non-secure state through the first SG instruction and execute the Non-secure callable function (Secure_LED_On).

Secure code:



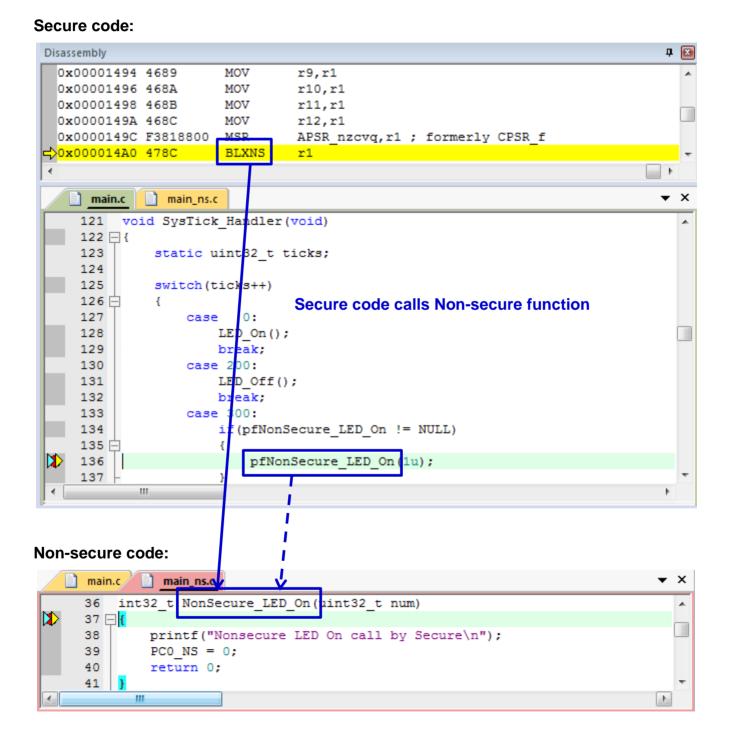
In the end of Secure function (Secure_LED_On), system switches from Secure state to Nonsecure state through a BXNS instruction.

Secure code:

0x000012CE B004 ADD sp,sp,#0x10 0x000012D0 BC80 POP {r7}	д 🗵
0x000012D2 BC02 POP {r1}	
0x000012D4 468E MOV lr,r1	
0x000012D6 4671 MOV r1,lr	
0x000012D8 4672 MOV r2,1r	
0x000012DA 4673 MOV r3,1r	
0x000012DC 46F4 MOV r12,1r	
0x000012DE F38E8800 MSR APSR nzcvq,lr ; formerly CPSR_f	
→0x000012E2 4774 BXNS lr	*
<	+ 📃
main.c main_ns.c	▼ ×
53 int32_t Secure_LED_On (uint32_t num)	
● 54 🖓 {	
<pre>55 printf("Secure LED On call by Non-secure\n");</pre>	
56 PBO = 0;	
57 return 0; In the end of Secure code and	
58 } switch back to Non-secure state	+
	Þ
Disassembly	д
78: Secure_LED_On(6u);	∓ 🔀 ▲
78: Secure_LED_On(6u); • 0x10040ABA 2006 MOVS r0,#6	₽ ⊠
78: Secure_LED On (6u); 0x10040ABA 2006 MOVS r0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24)	₽ ⊠
78: Secure_LED On (6u); 0x10040ABA 2006 MOVS r0,#6 0x10040ABC F000F8B2 BL \$Ven\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break;	д 1
78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL Wen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300;	д
78: Secure_LED On (6u); 0x10040ABA 2006 MOVS r0,#6 0x10040ABC F000F8B2 BL \$Ven\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break;	↓ ↓
78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL Wen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300;	₽ ₩ • • •
78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL Wen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300;	₽ ₩ • • • • •
78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: 0x10040AC0 9002 STR :0,[sp,#8] 4	• • •
78: Secure_LED On (6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL Ven\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300; Ox10040AC0 9002 STR 1 main.c main.c main_ns.c	• • •
78: Secure_LED On (6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: >0x10040AC0 9002 STR 20,[sp,#8] 1 1 main.c main_ns.c 68 void SysTick_Handler(void)	• • •
<pre>78: Secure_LED On (6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: 0x10040AC0 9002 STR 10,[sp,#8] 4 main.c main_ns.c 68 void SysTick_Handler(void) 69 = { 70 static uint32_t ticks; 71</pre>	• • •
<pre>78: Secure_LED On (6u); 0x10040ABA 2006 MOVS r0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: 0x10040AC0 9002 STR r0,[sp,#8] 4 main.c main_ns.c 68 void SysTick_Hangler(void) 69 { 70 static uint32 t ticks; 71 switch(ticks+4)</pre>	• • •
<pre>78: Secure_LED On (6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: 0x10040AC0 9002 STR :0,[sp,#8] </pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL</pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS 0x10040ABC F000F8B2 BL ;Ven\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300: 0x10040AC0 9002 STR t0,[sp,#8] main.c main_ns.c 68 void SysTick_Handler(void) 69 { 70 static uint32_t ticks; 71 72 switch(ticks++) 73 { 75 LED_On(7u);</pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300; 0x10040AC0 9002 STR c0,[sp,#8] </pre> <pre> main.c main_ns.c</pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: breax; 80: case 300 0x10040AC0 9002 STR c0,[sp,#8] main.c main_ns.c</pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL Ven\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: break; 80: case 300; 0x10040AC0 9002 STR 0,[sp,#8] * main.c main_ns.c 68 void SysTick_Handler(vcid) 69 { 70 static uint32_t ticks; 71 switch(ticks++) 73 { 72 switch(ticks++) 73 { 75 LED_On(7u); 76 break; 77 case 200. 78 Secure_LED_On(6u);</pre>	• • •
<pre>78: Secure_LED_On(6u); 0x10040ABA 2006 MOVS c0,#6 0x10040ABC F000F8B2 BL SVen\$TT\$L\$\$Secure_LED_On (0x10040C24) 79: breax; 80: case 300 0x10040AC0 9002 STR c0,[sp,#8] main.c main_ns.c</pre>	• • •

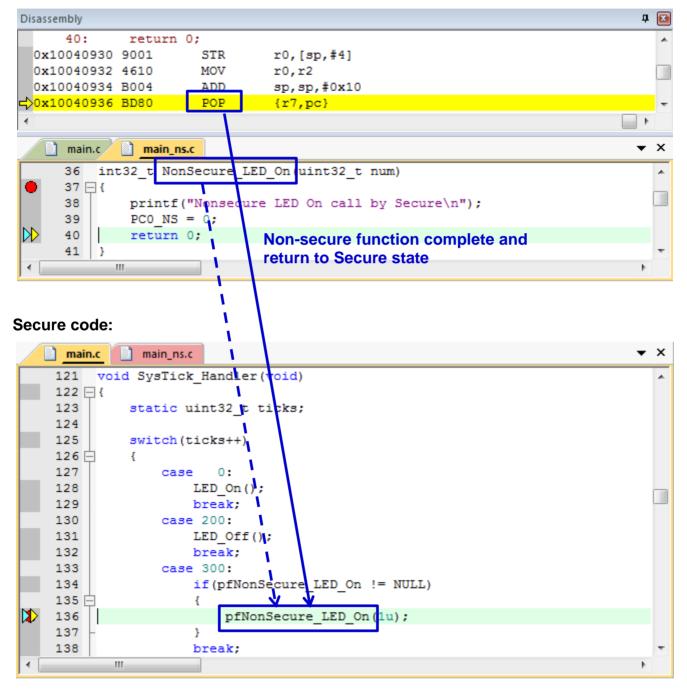
3.3.3 Secure Code Calls Non-secure Function

Secure code (main.c) calls Non-secure function (NonSecure_LED_On) by Non-secure function pointer (pfNonSecure_LED_On). The BLXNS instruction is the entry point system switches state from Secure state to Non-secure state.



Non-secure function (NonSecure_LED_On) is complete and returns to Secure state.

Non-secure code:



4 Sample Code

The TrustZone[®] sample code shows security attribution configuration and the state switch between Secure and Non-secure state. Figure 4-1 shows the SAU memory map which is defined by SAU. SAU defines the Non-secure region where data does not need protection and anyone can read or modify it, including Non-secure Flash, SRAM, peripheral and Non-secure callable Flash. Other regions not defined by SAU is Secure and data in the Secure region cannot be read and modified by everyone. SAU defined security memory map and IDAU memory map are compared with each other to determine the security attribution result. In the sample code, SAU defined attribution has the higher secure priority. The security attribution result is based on SAU configuration.

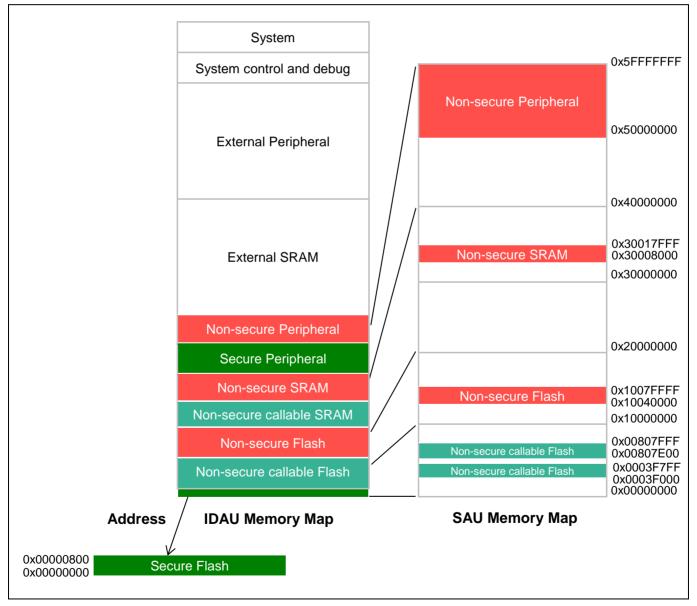


Figure 4-1 TrustZone[®] Sample Code SAU Memory Map

The TrustZone[®] sample code also shows Secure and Non-secure state switch. Secure and Non-secure codes configure their Systick independently. System enters Systick interrupt periodically. In Secure code, system toggles PB.1. In the Non-secure callable function, system toggles PB.0. In the Non-secure code, system toggles PC.1. When Secure code calls Non-secure function, system toggles PC.0. State switch between Secure and Non-secure state can be observed from GPIO status (high or low) change. Table 4-1 lists the GPIO and its related code state.

GPIO	Code State	
PB.0	Secure code calls Non-secure function.	
PB.1	Secure code.	
PC.0	Non-secure code calls Secure function.	
PC.1	Non-secure code.	

Table 4-1 TrustZone[®] Sample Code GPIO and Related Code State

4.1 Security Attribution Configuration

This section demonstrates how to configure resources security attribution by programing including memory map, Flash, SRAM, peripherals and peripheral interrupts.

4.1.1 Memory Map

Memory map security attribution is set by SAU. For example, plan the address 0x3F000-0x3F7FF for Non-secure callable function and set security attribution as Secure and Nonsecure callable.

```
/* Enable SAU */
SAU->CTRL = SAU_CTRL_ENABLE_Msk;
/* Set SAU region 3 */
SAU->RNR = 3;
/* Set SAU region 0 start address */
SAU->RBAR = (0x0003F000 & SAU_RLAR_BADDR_Msk);
/* Set SAU region 0 end address and attribute */
SAU->RLAR = (0x0003F7FF & SAU_RLAR_LADDR_Msk) | SAU_RLAR_NSC_Msk | SAU_RLAR_ENABLE_Msk;
```

4.1.2 Flash

Flash security attribution is set by the register NSCBA (Non-secure base address register, address 0x00200800). NSCBA sets the start address of Non-secure region in Flash and its read/write is through FMC. User can read the register SCU_FNSADDR (Flash Non-secure address register, address 0x4002F028) to get current NSCBA setting. For example, set the NSCBA value as 0x40000.

```
/* Non-secure code start address setup */
void FMC NSBA Setup(void)
{
    /* Check if NSBA value with current active NSBA */
    if(SCU->FNSADDR != 0x40000)
    {
        /* Unlock Protected Register */
        SYS UnlockReg();
        /* Enable ISP and configuration update */
        FMC DISABLE ISP();
        FMC_ENABLE_CFG_UPDATE();
        /* Setting NSBA when it is empty */
        if( FMC Read(0x200800) == 0xffffffful )
        {
           FMC Write(0x200800, 0x40000);
            /* Force Chip Reset to valid new setting */
            SYS->IPRST0 = SYS IPRST0 CHIPRST Msk;
        }
        while(1);
    }
```

4.1.3 SRAM

SRAM security attribution is set by the register SCU_SRAMNSSET (SRAM secure attribution set register, address 0x4002F024). For example, set the address 0x0-0xBFFF as Secure and set the address 0xC000-0x17FFF as Non-secure.

AN0019

```
/* SRAM Secure Attribution Configuration */
```

SCU->SRAMNSSET = 0x00000FC0;

4.1.4 Peripheral

Peripheral security attributions are set by the register SCU_PNSSET0-SCU_PNSSET6 (Peripheral secure attribution set register 0-6, address 0x4002F000-0x4002F018) and SCU_IONSSET (IO secure attribution set register, address 0x4002F01C). For example, set the UART1 security attribution as Non-secure.

```
/* Set UART0 Peripheral Secure Attribution */
```

```
SCU->PNSSET[3] |= SCU_PNSSET3_UART1_Msk;
```

Or set UART1 security attribution as Non-secure by SCU_SET_PNSSET().

```
/* Set UART0 Peripheral Secure Attribution */
```

```
SCU_SET_PNSSET(UART1_Attr);
```

4.1.5 Peripheral Interrupt

Peripheral interrupt security attributions are set by the register NVIC_ITNS0-NVIC_ITNS3 (Interrupt Target Non-secure Register 0-3, address 0xE000_E380-0xE000_E38C). For example, set the UART1 interrupt security attribution as Non-secure.

```
/* Set UART1 Interrupt Vector Secure Attribution */
```

NVIC->ITNS[1] |= BIT5;

Or set the UART1 interrupt security attribution as Non-secure by NVIC_SetTargetState().

/* Set UART1 Interrupt Vector Secure Attribution Configuration */

NVIC_SetTargetState(UART1_IRQn);

4.2 Secure and Non-secure State Switch

The system starts up in Secure code by default. This section demonstrates how Secure code is executed to Non-secure code. The Non-secure code can call Secure function and the Secure code can call Non-secure function, too.

4.2.1 Execute from Secure Code to Non-secure Code

Secure code:

Before executing Non-secure code, user needs to set Non-secure vector table address and Non-secure Main Stack Pointer, use a Non-secure function pointer and assign the value to Non-secure code Reset_Handler function. Use cmse_nsfptr_create intrinsic to clear LSB of Non-secure function address, then use Non-secure function pointer to call Non-secure function directly.

```
/* typedef for NonSecure callback functions */
typedef __attribute__((cmse_nonsecure_call)) int32_t (*NonSecure_funcptr)(uint32_t);
void Nonsecure Init(void)
{
    /* Non-secure function pointer */
    NonSecure funcptr fp;
    /* SCB NS.VTOR points to the Non-secure vector table base address. */
    SCB NS->VTOR = 0 \times 10040000;
    /* 1st Entry in the vector table is the Non-secure Main Stack Pointer. */
    TZ set MSP NS(*((uint32 t *)SCB NS->VTOR));
    /* 2nd entry contains the address of the Reset Handler function */
    fp = ((NonSecure funcptr)(*(((uint32 t *)SCB NS->VTOR) + 1)));
    /* Clear the LSB of the function address to indicate the function-call
       will cause a state switch from Secure to Non-secure */
    fp = cmse_nsfptr_create(fp);
    /* Non-secure function call */
    fp(0);
```

4.2.2 Non-secure Code Calls Secure Function

Secure code:

Secure code adds "cmse_nonsecure_entry" attribute for Non-secure callable function (Secure_LED_On).

```
/* Secure function and Non-secure code callable */
attribute__((cmse_nonsecure_entry))
int32_t Secure_LED_On(uint32_t num)
{
    printf("Secure LED ON call by secure\n");
    PB0 = 0;
    return num * 3;
}
```

Non-secure code:

Then Non-secure code can call Non-secure callable function (Secure_LED_On) which is provided by Secure code.

```
/* NonSecure Callable Functions from Secure Region */
extern int32_t Secure_LED_On(uint32_t num);
/* Non-secure code call Secure function */
void SysTick_Handler(void)
{
    Secure_LED_On(6u);
}
```

4.2.3 Secure Code Calls Non-secure Function

Non-secure code:

Secure code can call Non-secure function directly. The following is a Non-secure function.

```
/* NonSecure functions used for callback */
int32_t NonSecure_LED_On(uint32_t num)
{
    printf("Nonsecure LED On call by Secure\n");
    PC0_NS = 0;
    return 0;
}
```

Call Non-secure callable function and return Non-secure function address to Secure code when executing Non-secure code.

```
/* NonSecure Callable Functions from Secure Region */
extern int32_t Secure_LED_On_callback(void *callback);
void main(void)
{
    /* register NonSecure callback in Secure application */
    Secure_LED_On_callback(&NonSecure_LED_On);
```

Secure code:

Secure code stores the Non-secure function address in Non-secure function pointer and clear the LSB of Non-secure function address by cmse_nsfptr_create intrinsic, then Secure code can call Non-secure function directly by Non-secure function pointer.

```
/* typedef for NonSecure callback functions */
typedef __attribute__((cmse_nonsecure_call)) int32_t (*NonSecure_funcptr)(uint32_t);
/* NonSecure callback function */
NonSecure_funcptr pfNonSecure_LED_On = (NonSecure_funcptr)NULL;
/* Secure function for NonSecure callbacks exported to NonSecure application */
__attribute__((cmse_nonsecure_entry))
int32_t Secure_LED_On_callback(NonSecure_funcptr *callback)
{
    pfNonSecure_LED_On = (NonSecure_funcptr)cmse_nsfptr_create(callback);
    return 0;
}
/* Secure code call Non-secure function */
void SysTick_Handler(void)
{
    pfNonSecure_LED_On(1u);
}
```

4.2.4 Non-secure Security Attribution Check

Secure code provides Non-secure callable function for Non-secure code to call Secure function. It also provides parameter and return value. Secure function can check the memory security by cmse_check_adress_range intrinsic before reading or modifying any data to avoid the important data is stolen or broken.

Non-secure code:

If "ticks" variable value is greater than 600 then call Non-secure callable function to clear "ticks" variable value.

```
/* NonSecure Callable Functions from Secure Region */
extern void ResetTick(uint32_t* buf)
;
/* Non-secure code call Secure function */
void SysTick_Handler(void)
```

```
static uint32_t ticks;
if(tick>600)
    ResetTick(&ticks);
else
    ticks++;
```

Secure code:

This Non-secure callable function is used to clear the specified variable value to 0. Check if the variable value is located in the Non-secure region before it is modified. Clear the variable value to 0 if the variable address is in the Non-secure region and add 1 to the counter.

```
/* Secure function and Non-secure code callable */
uint32_t g_u32Counter = 0;

__attribute__((cmse_nonsecure_entry))
void ResetTick(uint32_t* buf)
{
    /* Check buffer space from Non-secure */
    buf = cmse_check_address_range(buf, 1, CMSE_NONSECURE);
    if(buf==NULL) return;
    /* Set buffer value to 0 */
    *buf = 0;
    /* Record Non-secure Systick reset counter value */
    g_u32Counter++;
}
```

5 Conclusion

In the IoT (Internet of Things) application, devices not only can communication with each other through the internet but can be attacked through the Internet. The security is an important topic to protect device and information. The Arm[®] TrustZone[®] technology partitions hardware into Secure and Non-secure world. The device itself is reliable and Secure code is executed in Secure world. The information from Internet is unreliable such that Non-secure code is executed in Non-secure word.

Through IDAU which defines fixed memory map security attribution with the user configurable SAU, all of microcontroller resources can be configured to Secure and Non-secure including memory map, Flash, SRAM, peripherals and peripheral interrupts. After planning the security attribution of these resources, the Non-secure world can only access Non-secure memories and resources, while the Secure world can access all memories and resources, including secure and Non-secure.

The security attribution can be set by programming or a configuration wizard interface in the Keil[®] MDK development environment. The code can switch between Secure and Non-secure state. An authentication method can be added to Secure code to certify if the Internet information is trusted so as to provide authority for Non-secure code to access Secure resources. With TrustZone[®] hardware architecture and software authentication, the IoT application can be implemented safely and flexibly.

Revision History

Date	Revision	Description
2018.08.31	1.00	1. Initially issued.

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