STM32-AI RELOCATABLE with ThreadX Module Manager and related Module application

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1. PURPOSE & SCOPE

1.1. Purpose

This Application Note demonstrates how to build and run a sample application exploiting the STM32-AI RELOCATABLE running in a ThreadX thread together with the AZURE RTOS ThreadX Module Manager functionality.

To add the connectivity and file system capabilities the NetXDuo TCP/IP network stack and the FileX embedded file system middleware was also included.

This application was developed starting from the original application part of the STM32 U5 FW official delivery that can be found in \STM32Cube_FW_U5_V1.1.0\Projects\NUCLEO-U575ZI-Q\Applications\ThreadX\Tx_MPU.

The application shows how to download from and FTP server, and run within a thread, an STM32-AI RELOCATABLE network and weights generated as binary files. This allows to update “on the flight” the AI network and/or the related weights.

Is also shown the Module Manager capability to download from an FTP server, as a binary file, the Module and to execute it from memory and from file, other than simple “execution in place”.

1.2. Scope

This Application Note is specifically built for the STM32 U585 processor mounted on the evaluation board MB1551-U585AI-C02 for more information please visit https://www.st.com/en/evaluation-tools/b-u585i-iot02a.html.

The IDE and compile used is IAR EWARM for more information please visit https://www.iar.com/products/architectures/arm/iar-embedded-workbench-for-arm/

The current application doesn’t demonstrate any security/encryption aspect of the U5 MCU.

1.3. Background

The STM32Cube.AI is a set of tools capable to generate a pre-trained relocatable (PIC & PID) AI network with its related weights both generated in the form of relocatable binary files.

The AI binary files (network and weights) are generated thanks to the stm32ai Command Line Interface (CLI) starting from an .h5 network description file.

The ThreadX Module is a Position Independent Code and Data library (aka PIC/PID) built as an independent single binary file. It has the capability to communicate and exchange information with the main resident application running the ThreadX Module Manager. The Module can be un/loaded at run time by the resident application.

For more information about STM32Cube.AI please visit https://stm32ai.st.com/stm32-cube-ai/

For more information about Microsoft ThreadX RTOS please visit https://docs.microsoft.com/en-us/azure/rtos/threadx/

For more information about Microsoft ThredX Module feature please visit
https://docs.microsoft.com/en-us/azure/rtos/threadx-modules/

2. GETTING STARTED

2.1. What this demo does

The demo, after start first

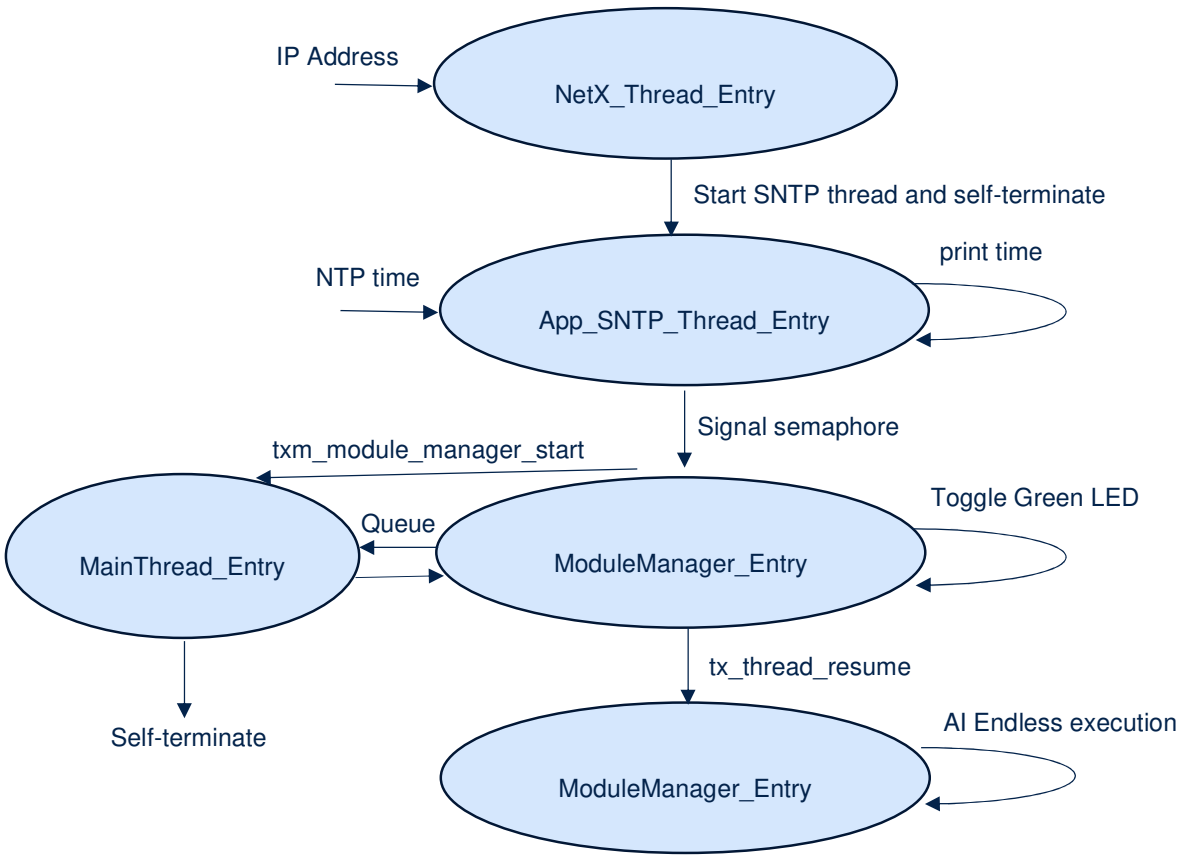
- try connecting to the WiFi network with the provided credentials (network SSID and password)
- than after having acquired from the router its IP address through the DHCP protocol, it tries to connect to SNTP server in order to acquire the current GMT time and set the correct system time
- after that it format the NOR Flash File System (if not already done previously)
- than it contacts the indicated FTP server IP address and connect it with the user provided credentials to download the files containing:
    - The AI Network
    - The AI Weights
    - The Module library

- If the AI network and weights files are downloaded successfully both are stored in the file system overriding the former, if already existing, then are flashed. After that AI starts executing in its own thread.
- If the FTP server cannot be reached the application look for the AI Network and weights in the local file system, if found, both the files are flashed in internal flash memory and executed.
- if the Module file is downloaded successfully, the Module file already present on NOR Flash File System (if any) is overridden by the just downloaded file
- if for any reason the Module file download fails (typically because of wrong FTP credential/IP or missing file on the FTP server) the demo runs automatically the Module file already present on Flash File System, if any was previously downloaded.
- The Module sends through a queue some messages to the resident application and finally it deliberately executes a memory access violation triggering an exception in the resident application.
- After having completed the Module execution and having released the related Module resources the demo prints periodically every 10Sec the current system time (GMT) and the green user led blinks every 500mSec
- The AI continues to run every 1 Second processing a fixed pattern of data and checking the output. Is also possible to compile the application to process a random input pattern.

2.2. **The Demo architecture**

The Module Manager resident application is split over 4 threads plus 1 thread for the Module:

1. The NetX_Thread_Entry () receiving the IP address change notification and acting as a trampoline for the other application threads.
2. The App_SNTP_Thread_Entry() connecting the Network Time Protocol server getting the GMT time and setting the system time to RTC. The thread, after having accomplished the SNTP synchronization signal the thread ModuleManager_Entry() and enter in a loop displaying periodically the current GMT date and time every 10 Sec.
3. The ModuleManager_Entry(), this thread after having allocated the resources needed by the Module Manager and the related Module, wait for the semaphore signaled by the App_SNTP_Thread_Entry(). After the semaphore is signaled, meaning IP address and NTP time acquired, it initializes the file system (formatting the disk if needed), contact the FTP server, download the Module and execute it.
4. Module MainThread_Entry() is the thread executed within the Module memory space when the Module is started by the Module Manager resident application thread ModuleManager_Entry().
5. AIThreadEntry is the thread executing the AI Network, it is started by the ModuleManager_Entry -acting as a “trampoline” thread- after having downloaded the Network and the Weights binary files if available on FTP server.
6.



Required Hardware

- B-U585I-IOT02A Rev C (code MB1551-U585AI-C02)
- Usb 2.0 male to Micro USB male cable

Required software

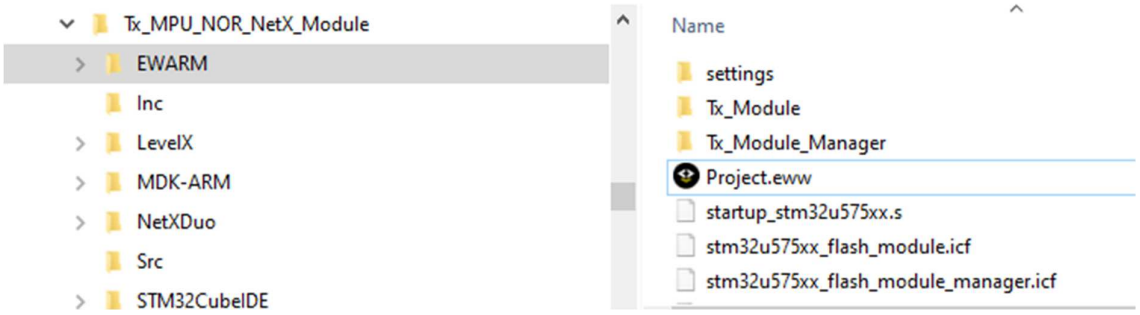
- Tera Term terminal
- STM32CubeProgrammer (V2.8..0 or later)
- IAR Embedded Workbench for ARM (V.8.50.6 or later)
- Patch for U5 support (v.8.50.8 or later) for IAR EWARM
- ST Link USB Driver
- Universal FTP Server

3. DEMO COMPILATION

3.1. Demo Unzip and build

After having unzipped the files, (preferably on C: to avoid long path issue) execute the below steps:

1. Double click on the master EWARM project



In order to connect to the available WiFi network please enter the SSID and password in the file "mx_wifi_conf.h"

#define WIFI_SSID "MyWiFiSSID"

#define WIFI_PASSWORD "MyWiFiPassword"

In order to connect to the FTP server please take note from the FTP server application the hosting machine IP address and set the FTP username and password. The same IP address, username and password must be set in file "app_netxduo.c"

#define FTP_SERVER_ADDRESS IP_ADDRESS(192,168,1,10)

#define FTP_ACCOUNT "MyFTPAccount"

#define FTP_PASSW "MyFTPPassword"

In case of need the module file name can be changed in file "app_threadx.h" as below:

#define MODULE_FILE_NAME "Module.bin"

The AI Network and weights files name can be changed in the same file as below:

#define AI_NETWORK_FILE_NAME "network_rel.bin"

#define AI_WEIGHTS_FILE_NAME "network_data.bin"

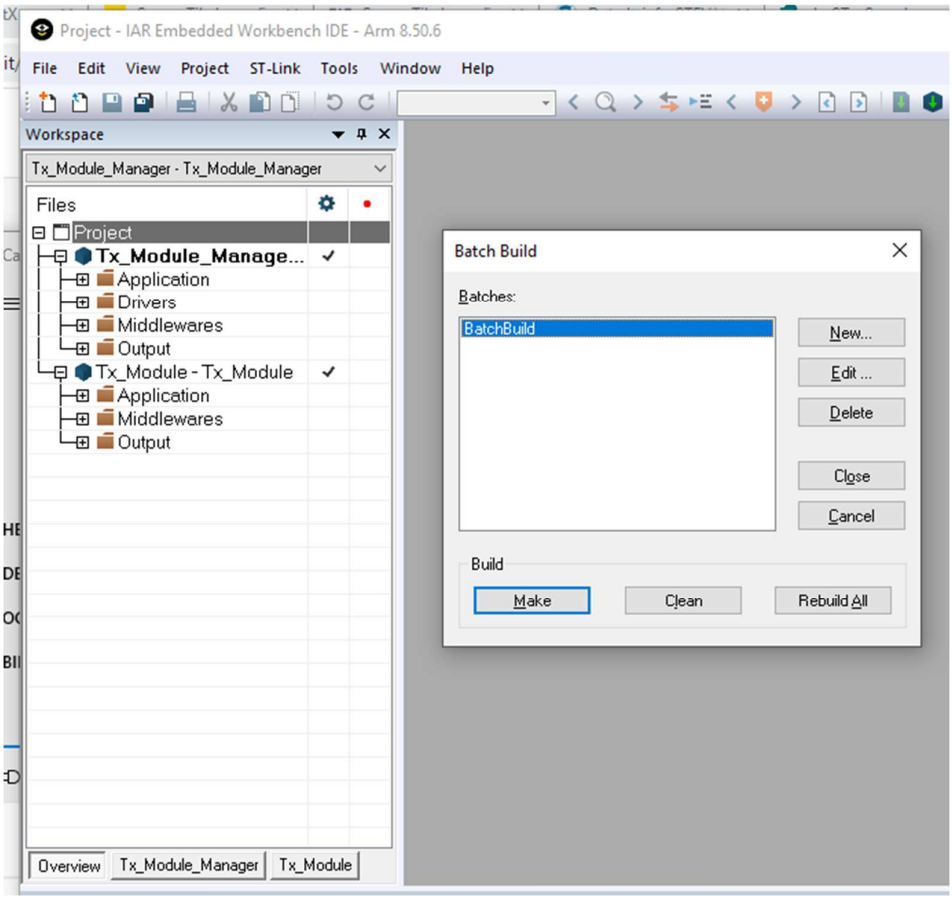
The pre-generated AI Network files< network_rel.bin > and < network_data.bin >are in:

<….\DEMO_AI_RELOCATABLE_THREADX\X-CUBE-AI>

After build the generated Module binary files is in:

<DEMO_AI_RELOCATABLE_THREADX\Projects\B-U585I-IOT02A\Applications\ThreadX\Tx_MPU_LevelX_NetX_Module\EWARM\Tx_Module\Exe>

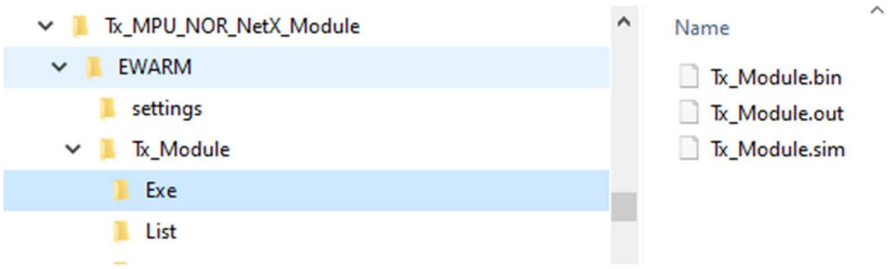
After having set the above parameters in the src files, from the EWARM project press F8 key or select from textual menu Project->BatchBuild. This will build both the projects “Tx_Module_Manager” and “Tx_Module”



After build two binary files will be produced:

- Tx_Module_Manager.out containing the resident application to be flashed on the board

- Tx_Module.bin containing the Module code in form of PIC & PID (aka Position Independent Code/Data) library. This file needs to be copied on the external FTP server.

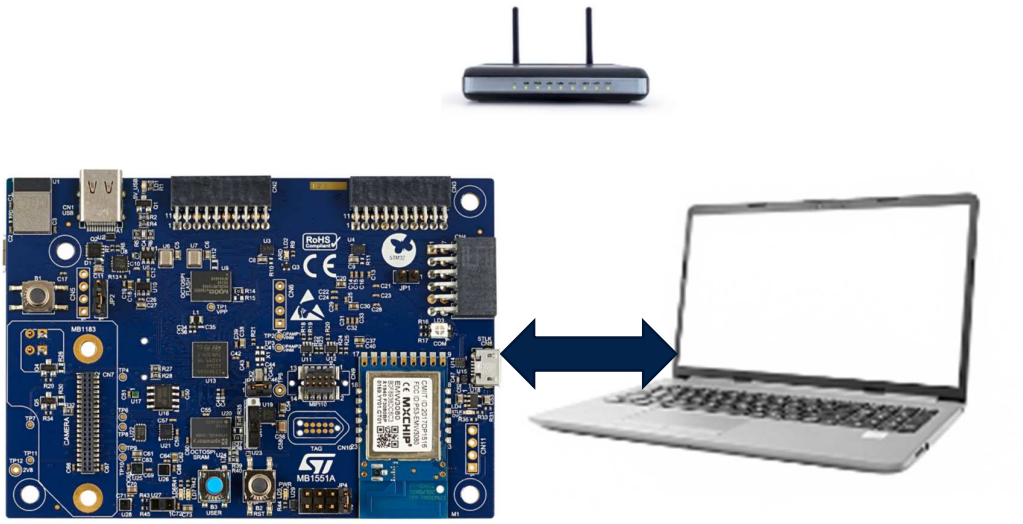


In case of need the relocatable network files can be re-generated thanks to stm32ai CLI command tool with the command below launched from the power shell (please notice that the STM32AI tools should be installed and the PATH of <stm32ai> should be set)

<stm32ai generate -m .\vibration_model_mfcc.h5 -c none --series stm32u5 --binary --relocatable --no-c-files --allocate-inputs --allocate-outputs -o .\prv_no_src -n network>

4. DEMO EXECUTION

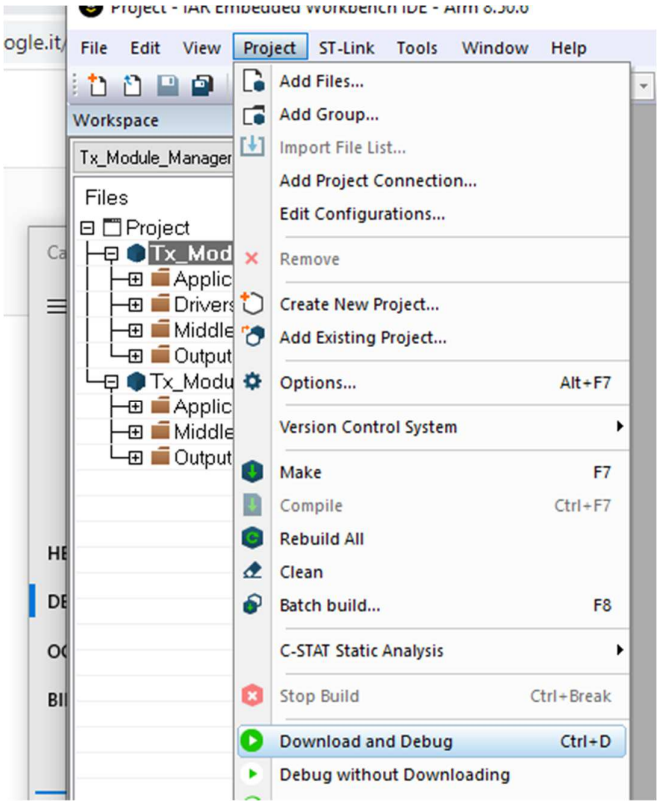
4.1. Overall, Hardware setup



- The U5 board
- a laptop running FTP server, IAR EWARM and TeraTerm
- A router (possibly) with internet access

4.2. Resident Module Manager application flashing

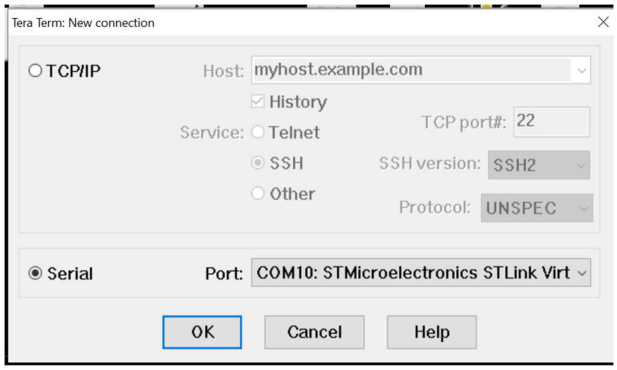
After having selected the project Tx_Module_Manager press Ctr+D the debugger will start, and the resident application will be flashed.

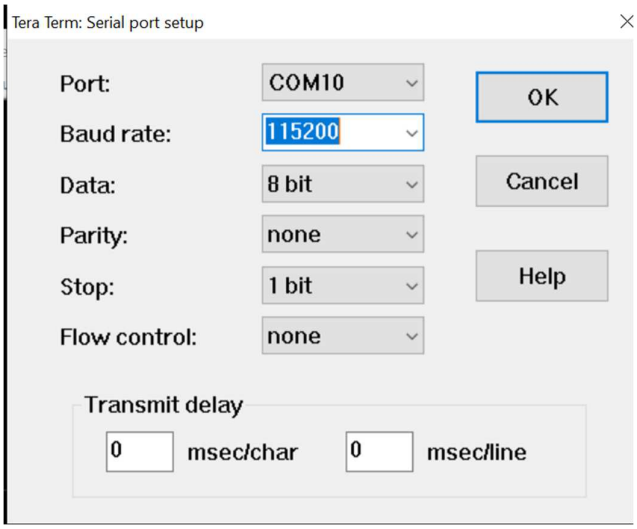


4.3. **FTP Server and Tera Term setup**

Before to run the Module Manager resident application, it needs to setup the FTP server setting the FTP account and password and coping the Tx_Module.bin file in the FTP server directory.

It needs also to connect the TeraTerm to the board in order see the application execution log. The serial speed 115200 bps





After having setup the FTP server and the TeraTerm the Module Manager application can be run and the below execution log should be shown on TeraTerm

Please notice that the COMn port number is self-assigned by widows USB enumerator so the port number can vary.

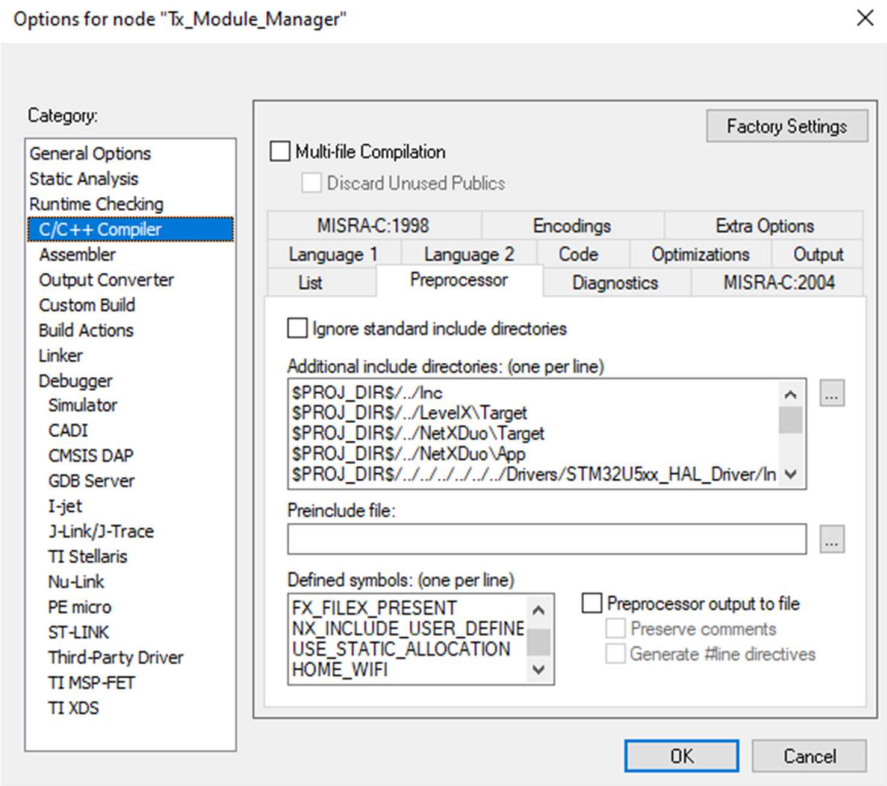
```
============================================================
|                 Demo AI & Module Started                 |
============================================================
Nx_SNTP_Client application started..
Waiting for IP address ...
STM32 IpAddress: 192.168.1.3
SNTP client connected to NTP server : < time1.google.com >
15-11-2022 / 09:49:49

SNTP update :
Nov 15, 2022 9:49:49.816 UTC

User available NOR Flash disk space size : 67006464 bytes.

Created the FTP Client

Connecting the FTP Server: 192,168,1,5 ...
Connected to the FTP Server
Enabled FTP Client Passive Mode
Opened the FTP client Module.bin file
Created Local File Module.bin file
Opened Local File Module.bin
Downloaded from FTP file: Module.bin fsize: 2984
Closed the FTP client Module.bin file

Created the FTP Client

Connecting the FTP Server: 192,168,1,5 ...
Connected to the FTP Server
Enabled FTP Client Passive Mode
Opened the FTP client network_rel.bin file
Created Local File network_rel.bin file
Opened Local File network_rel.bin
Downloaded from FTP file: network_rel.bin fsize: 14124
Closed the FTP client network_rel.bin file
Flashing from file: network_rel.bin, size: 14124, to Flash Addr: 0x80c0000

Created the FTP Client

Connecting the FTP Server: 192,168,1,5 ...
Connected to the FTP Server
Enabled FTP Client Passive Mode
Opened the FTP client network_data.bin file
Created Local File network_data.bin file
Opened Local File network_data.bin
Downloaded from FTP file: network_data.bin fsize: 42120
Closed the FTP client network_data.bin file
Flashing from file: network_data.bin, size: 42120, to Flash Addr: 0x80c4000

#
# AI system performance measurement (RELOC) 2.0
#
Compiled with IAR 9 (build 275)
STM32 Runtime configuration...
 Device       : DevID:0x0482 (STM32U575/585) RevID:0x2001
 Core Arch.   : M33 - FPU  used
 HAL version  : 0x01010000
 SYSCLK clock : 160 MHz
 HCLK clock   : 160 MHz
 ICACHE       : True
Module <Module One> is loaded from file Module.bin executed from address: 0x20034DC0
Module code section size: 2984 bytes, data section size: 11232
Module Attributes:
  - Compiled for IAR EW compiler
  - Shared/external memory access is Enabled
  - MPU protection is Enabled
  - User mode execution is enabled for the module

Module Manager execution is started
Module is executing: Writing to ReadWrite Region
 Timestamp    : SysTick + DWT (HAL_Delay(1)=0.952 ms)

Instancing the network (reloc)..

AI binary network image (0x080c0000)
  c-name        : "network"
  activations   : 736
  weights       : 42120
```

5. DEMO CUSTOMIZATIONS

5.1. WiFi customization

The demo offer two pre-defined wifi setup to connect to two different networks, typically the home WiFi and the work WiFi.

One of the two pre-defined networks can be chosen by means of definition of the compilation environmental variable HOME_WIFI



5.2. **Module “in place or from file execution”**

The demo by default is configured in order to download the file containing the module from an FTP server, than to execute it from SRAM. The demo can be also configured in order to execute the Module from SRAM, after having loaded it from a Flash, or to execute the Module directly from the Flash memory address where it was flashed (aka “execution in place”)

If the definition:

#define MODULE_LOAD_FROM_FILE

In file app_threadx.h is defined the Module is loaded from the file previously downloaded from FTP, otherwise the Module is loaded from the Flash address specified at

#define MODULE_FLASH_ADDRESS &module_entry // from linker script

5.3. **File System backend customization**

The demo can be customized to use as a File System backend driver the RAM driver running the FS on the internal SRAM. Or, by default, the demo run the FS on NOR Flash.

Default definition in app_filex.h:

#define NOR_FLASH_FS

6. CONCLUSIONS

6.1. The Modules advantages

As seen above the Modules offer a variety of advantages in terms of application upgrade and update, possibility to add new features on the flight etc. This could be particularly useful for IoT connected applications.

In the current demo all the security aspects are not addressed, showing just a simple module memory isolation using MPU. The security aspects involve additional HW and FW and also third-parties for authentication, they can be the subject of a separate demo.

6.2. The STM32AI Relocatable advantages

As demonstrated by the demo the STM32AI network compiled in form of self-contained binary files offer the below listed advantages in comparison with the traditional embedded AI approach:

- **Upgradability**: the AI network and weights can be updated on the flight
- **Memory optimization**: the AI network and weights can be placed or moved to any address in memory according to the application needs. In case of need the AI can be also offloaded from internal memory and stored in the file system for a later reuse

7. REFERENCES & DEFINITIONS

7.1. References

7.1.1. External References

Definition	Link
ThreadX Module doc	*https://docs.microsoft.com/en-us/azure/rtos/threadx-modules/chapter1*
Module Preamble ARM M33	*https://docs.microsoft.com/en-us/azure/rtos/threadx-modules/appendix#cortex-m33-processor*
IAR IDE and Compiler toolchain	*IAR IDE and Compiler toolchain https://www.iar.com/products/architectures/arm/iar-embedded-workbench-for-arm/*
B-U585I-IOT02A STM32 board	*https://www.st.com/en/evaluation-tools/b-u585i-iot02a.html*
STM32CubeProgrammer	*https://www.st.com/en/development-tools/stm32cubeprog.html*
Window FTP Server	*https://www.windowscentral.com/how-set-ftp-server-windows-10*
Tera Term	*https://tera-term.en.softonic.com/*

7.1.2. Internal References

7.2. Acronyms & Definitions

7.2.1. Acronyms

<List the acronyms used in your document in the table below. Refer users to the ST Glossary for further common definitions. Another useful approach for readers is to define an acronym the first time it is used. >

Acronym	Definition
PIC	*Position Independent Code*
PID	*Position Independent Data*
EWARM	*IAR IDE and Compiler toolchain*
DHCP	*Dynamic Host Configuration Protocol*
DNS	*Domain Name System*
SNTP	*Simple Network Time Protocol*
FTP	*File Transfer Protocol*
ELF	*Executable and Linkable Format*

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7.2.2. Definitions

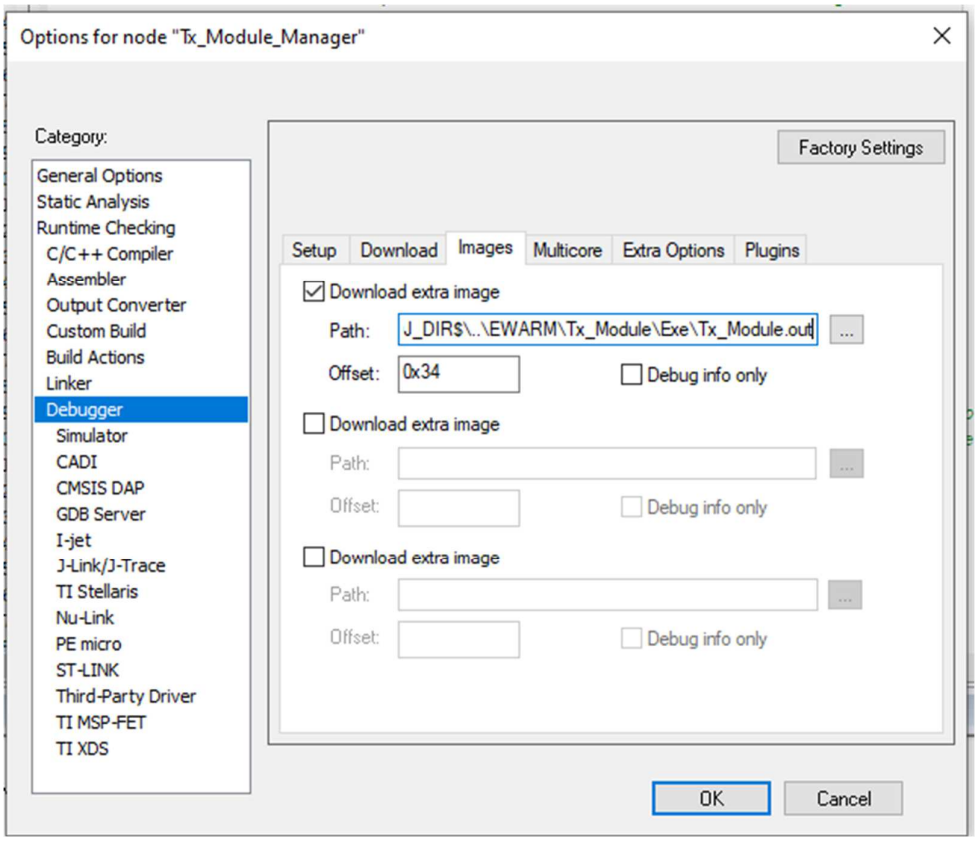
Term	Definition

APPENDIX: TROUBLESHUTTINGS AND HINTS

1. **WiFi connection and router IP address reservation**:
   It is advisable to setup the router in order to reserve an IP address for the machine hosting the FTP server, doing so will prevent the DHCP server running on the router to change dynamically the host PC and board IP address.

2. **NOR Flash File System corruption**:
   In case of abrupt interruption of the application (break or abort from IDE or HW reset) with opened files it can happen that the NOR flash file system gets corrupted, the application try to fix it automatically formatting the NOR if needed. In the unlikely event of FS corruption not detected by the application the FS formatting can be forced modifying the file app_filex.c

3. **Module direct flashing using EWARM IDE**:
   If, for any reason, the usage of the FTP server is not possible the Module can be flashed directly on the board by the EWARM IDE clicking on the check box “Download extra image” and specifying the **Module image ELF file** (not the binary) as shown below



The module will be flashed at the address 0x8080000 as specified in the Module linker script file “stm32u575xx_flash_module.icf”

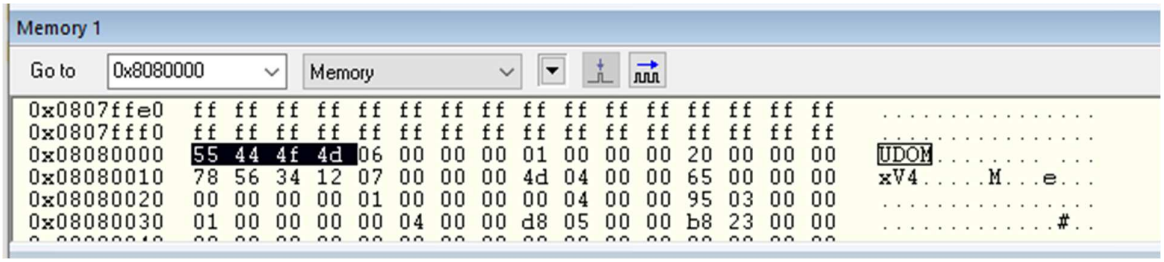
```
/*-Memory Regions-*/
define symbol __ICFEDIT_region_ROM_start__ = 0x08080000;
```

So that the Module will be flashed by the EWARM IDE together with the resident Module Manager application. As shown below the Module signature pattern “55 44 4f 4d” indicating the first bytes of the Module preamble is placed at flash address 0x8080000.
Once the module is in flash memory it can be executed in place by means of calling the “txm_module_manager_in_place_load()” commenting in file app_threadx.h the

#define MODULE_LOAD_FROM_FILE

Alternatively it can be loaded and executed in SRAM by means of calling “txm_module_manager_memory_load()” by means of commenting in file app_threadx.h the

#define MODULE_EXECUTE_IN_PLACE



4. **Module Debugging and step by step execution**:
   In order to enable module debugging the debugger needs the below listed informations:

   - module debugging symbols that can be found on the Module ELF file
   - module code offset (typically 0x34) from the module preamble start address (0x8080000)

   Because of the above requirements the Module code must be flashed together with the Module Manager application as shown above at point 3, and it must be executed in place to allow Module code debugging (same load and execution address 0x8080000 despite its PIC/PID nature).

When compiling for debugging purposes don't forget to disable all the Module Manager and the Module compiler optimizations: