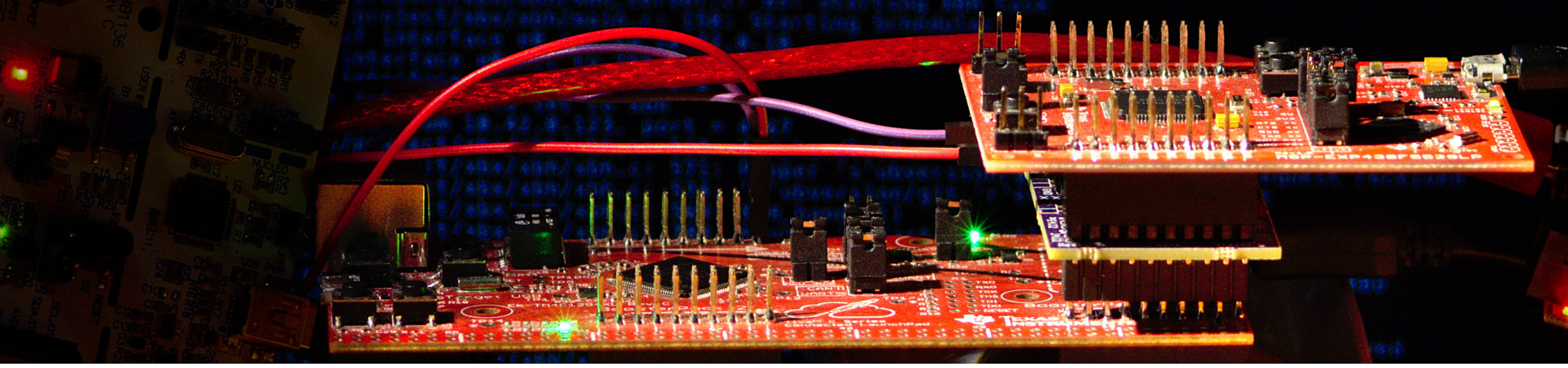

XXBX Device Under Test – XBD

XBD User Guide v1.0

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1 Introduction

XBD has two main software components: the Bootloader and the Application. It is initially flashed with the Bootloader, which contains the Hardware Abstraction Layer and can perform rudimentary functions such as initializing the I2C module, Clocks module, GPIO ports, Universal Serial Communication Interface (USCI), etc and also be able to report timing measurements for calibration and receive the Application over I2C. On the other hand, the Application contains the wrapper for the algorithm and helper functions to set up the stack, parameters to be used by the algorithm, and to signal execution to the XBH. The RAM usage is measured by the Application by counting the available stack and painting it with Canaries, executing the algorithm, and then reading the stack again to see how much memory has been used.

The XBD software remained largely identical to that in original XBX. Most of the changes were limited to refactoring or adding AEAD support.

The substantially more comprehensive self-test suite to verify correctness of the primitive implementations from SUPERCOP replaced the simplified version found in XBX, as we wanted to retain this aspect of SUPERCOP and did not want to write our own test for AEAD.

Unfortunately this leads to substantially longer execution times and precludes operation with smaller devices especially for AEAD, which was probably the original XBX team's motivation for writing a simplified check.

For AEAD, the test requires two large buffers, one for input ciphertext/auth data and one for output, and multiple smaller buffers for keys, secret number, as opposed to hash functions, which only need a large buffer for the input and a substantially smaller buffer for the hash, with the largest output being 512 bits (64 bytes). In addition AEAD primitives require multiple smaller buffers for various parameters defined in the CAESAR interface, each with padding in order to detect overruns. The buffers and limits we assigned for AEAD are:

- Message
- Associated Data (Associated Data+Message must be less than 2048 bytes)
- Ciphertext, which is the size of Message+Associated Data plus additional bytes for authentication. Additional bytes is limited to 128 bytes.
- Secret Bytes (64 bytes)
- Public Bytes (64 bytes)
- Key Bytes (64 bytes)

Some primitives had unreasonable sizes for parameters such as Trivia-128v1 which specified slightly over 512kiB of additional bytes to the output, which is well over the total memory of most microcontrollers We decided on these limits since we deemed them the maximum reasonable for an embedded platform, although we leaned towards larger sizes unlikely to be found in an embedded environment in order to include more primitives. Embedded devices might also use larger than ideal primitives for interoperability reasons.

Other aspects of the XBD code were also modified to make most of the XBD code as operation-agnostic as possible, except for the test code. References to hash functions were removed in code that was generic to all operations.

In order to support a new operation already supported by SUPERCOP, changes are limited to modifications to the script used to generate the tests in order to allocate memory in order to fit our more restricted framework and code to unpack message payloads to set the appropriate buffer pointers.

The software for the XBD is largely the same as the original XBX. Self-test implementation was replaced with SUPERCOS's (?). The XBD software factored out hash-specific code to make it easier to add other operations. There was added a AEAD payload processing. XBH doesn't know anything about the operation under test, just routes it blindly to XBD from XBS. XBD must know what is being in run order to unpack parameters and messages The XBD code consists of a small bootloader that is flashed once to XBD that performs basic calibration and selfprogramming of the primitive implementations over the communications channel. After that, application download and execution is handled over a communication channel established between the bootloader and the benchmarking harness.

2 Hardware Abstraction Layer

3 Boot Loader

3.1 Overview

The bootloader for the XBD is located in xbs_xbd/embedded/xbd_bl.c. It is compiled with HAL and its operation for XBH to XBD communication is highlighted in xbs_xbd/embedded/xbd_app.c. Theres some utilities defined in xbs_xbd/embedded/xbd_af.c. The operations and hash to use are located in xbs_xbd/embedded/xbd_op.c. Bootloader can be debugged using console on XBD.

3.2 Stack Usage Measurement

The HAL contains two functions that allow for stack measurement: paintStack and countStack. PaintStack paints the free stack area with a known pattern, called a canary bird. Then the function to be benchmarked is called and after it returns, countStack counts the number of canary birds that did not survive. This gives the maximum amount of stack used by the benchmarked function. Combined with the static RAM requirement obtained from the application binary and the known RAM requirement of the AF, the total RAM consumption of a triple [Algorithm, Compiler, Options] can be measured. The file embedded/xbd/xbd_op/crypto_aead/XBD_O H.c provides a means to measure the stack usage. The steps are as such, paint stack, run code, check stack, report to XBD. There is also apparently a size command that gets the ROM usage and RAM usage.

3.3 XBH-XBD Communication

3.3.1 I^{2}C Interface

3.3.2 XBH-XBD Protocol

Much of the core XBH code dealing with the XBH ¡-¿ XBD protocol and packet formats was reused, with some rewriting to conform to preferred coding conventions, such as using C99 inttypes.h instead of custom typedefs. From XBH command was sent in such a way as to contain the opcode and the CRC value. Then XBD responded by sending back the command plus the data and the 2 byte CRC value. Some of the possible commands are XBD04SBR for properly starting bootloader, and XBD04TCR for timing calibration request. Theres many more defined in the codebase.

3.3.3 General Purpose IO

3.3.4 Reset

Debug

The XBDs also contain UART debug interface that can be used to test functionality of the program. Part of work also involved fixing the debug interface on the original MSP30 XBD. An important learned lesson here is that turning on the specific debugging output resulted in execution delays which affected the functioning of the system and caused errors related to I2C communication.

4 Application

5 Board Specific Changes

5.1 TI MSP430F5529 LaunchPad^{TM}

Much of our previous work on original XBX for the MSP430FG4618 was reused, and the work was mostly altering pinouts and adapting to the new MSP430-GCC [?] toolchain, which had substantial differences to the older MSPGCC toolchain [?].

We decided to clock the MSP430F5529 at 16MHz, matching the clock rate on the AVR platforms in original XBX. The clock initialization on the MSP430F5529 is more complicated, and we used code from the Energia [?] project to handle this. The digitally controlled oscillator (DCO) in the MSP430F5529 does not run at exactly 16MHz, but mixes two frequencies to get an average at the specified frequency. This causes jitter and has implications for accurate measurement when cycles are measured externally, however the impact is likely to be negligible for the purpose of comparing algorithms. This is a motivation for using cycle counters where available if more precise measurements are needed, however.

In order to support LTO, we had to mark the interrupt handler for resetting the XBD explicitly as used using GCC attributes. Attributes are a compiler-specific C extension used to apply a property to a C function or variable, that is not in standard C. Without this attribute, LTO would optimize out the interrupt handler.

5.2 TI MSP430FR5994 LaunchPad^{TM}

Another significant aspect for the XBDs in general is their placement of the Bootloader and the Application in their flash memory. More specifically regarding MSP430FR5994, the memory is organized as follows.

5.2.1 Memory Map

fig is in 746-paper.

As we can see from the memory organization, the interrupt vector is placed in the Flash memory and so the memory is not contiguous. Currently the bootloader is being placed at address 0xE810 which leaves 6k for the bootloader, the Applicationloaded to 0x4000 which means its size can be 43024 bytes.future improvement here would be to place the bootloaderHIGH FRAM and leave the full 49k LOW FRAM for only the Application. This would allow for heavier sized algorithms tobenchmarked. This restriction also limited the size of the algorithms that could be run on this XBD (discussed later in the Results section).

MSP430FR5994 (the new XBD) is similar to MSP430F5529 (original XBD) however there were some changes that needed to be accounted for.

One of them was the standardization of the 16-bit control registers as opposed to the 8-bit registers in the original XBD and changes in some register naming conventions. The clocks system module on the new XBD allows for only specific discrete frequencies but the original XBD used a programmable multiplier to allow for more selectable range of frequencies. The original XBD used a 32-bit register (2 16-bit concatenated registers) in the RTC for busy looping for 1 sec. during timing calibration. This was not possible on the newer XBD since the RTC no longer allowed for concatenating two registers and the module could not source from the system clock (only a fixed 32KHz clock). The solution for this was to use a Timer sourced from the system clock with a wrap around interrupt. Usage of interrupts is okay here since timing calibration is done in the bootloader mode and not during algorithm execution. The timing calibration measurements are only done to check if the XBD is running at the set frequency. The actual execution times however are measured by the XBH using its own 120 MHz timer to be consistent with other XBDs timing measurements.

5.2.2 Flash

5.2.3 Using AES Peripherals

Most of the algorithms have AES as their underneath function during encryption and decryption. Some of them use total AES encryption, some others use single round AES and some others single round AES without XOR of key.

Fig 6. Functions in AES Rounds

To do the above implementation of the AES the algorithm has a software implementation of AES which does all the functions in a similar way mentioned below KeyAddition(a,rk[0],BC); for(r = 1; r ¡ ROUNDS; r++) Substitution(a,S,BC); ShiftRow(a,0,BC); MixColumn(a,BC); KeyAddition(a,rk[r],BC); Substitution(a,S,BC); ShiftRow(a,0,BC); KeyAddition(a,rk[ROUNDS],BC); While implementing algorithm on the microcontroller it runs a AES program that has the above programs, on MSP430-5529 while the algorithms are implemented during both encryption and decryption the program is called and AES implementation is done. The same can be done with MSP430-5994 as well but main advantage with this microcontroller is it has in built AES accelerator which can be utilized instead of the software AES implementation.

figs in 746 paper

The AES accelerator is present in some of the microcontrollers like MSP-430 5994 which performs the both AES encryption and decryption of 128 bit message data with different sizes of the key(128, 192 , 256bits) that is given to it. AES accelerator has different features: - AES encryption for 128 bit can be done in 168 cycles, 192 bit in 204 cycles, 256 bit in 234 cycles. - AES decryption can be in a similar fashion as encryption but for only 192 bit it takes 206 cycles. - Key expansion for encryption and decryption can be done on the fly. - Key generation for decryption can be offline. - DMA support for ECB, CBC, OFB, and CFB cipher modes. - The input data, output data and key can be accessed either as byte or word. But the issue is we can not mix both word and byte access during the time of reading or writing the data to the registers. - AES ready interrupt flag.

Registers in the block diagram: AESADIN, AESAXDIN: The data that needs to go in to the AES module as input is given into this registers. AESAKEY: The cipher key given is loaded into this register. AESADOUT: The output can be read out from here. Encryption in Accelerator: The plain text that is given in the AESADIN in subjected to rounds of transformations along with using the key located in AESAKEY and then the ciphertext is produced at the AESADOUT. Decryption in Accelerator: AESAXDIN now has the ciphertext which is subjected to rounds of transformations along with the cipher key that is available at AESAKEY and then plain textproduced at the AESADOUT.

5.3 TI MSP432P401R LaunchPad™

5.4 TI Stellaris® LM4F120 LaunchPad

Much of the work assembling the toolchain, sorting out platform quirks, and sorting through licensing on the TM4C1294 XBH applied to the TM4C123.

Open On-Chip Debugger (OpenOCD) is a tool used to program and debug various chips and boards, including the Tiva-C boards used as the XBH and an XBD [**?**]. Currently, it does not support multiple Texas Instruments In-Circuit Debug Interface (TI-ICDI) attached to the same PC. We wrote a patch [**?**] in order to distinguish different TI-ICDI devices by serial number.

We encountered some issues programming the primitive implementations into the XBD. The IHEX files containing the code to be downloaded to the XBD contained holes, which are unused memory areas that are not specified in the file, making the defined memory locations noncontiguous. The original XBS software did not properly take these into account, and would load nonadjacent blocks of code adjacently. This was fixed in the XBS rewrite.

5.5 TI Tiva™ C Series TM4C123G LaunchPad

5.6 ST Microelectronics NUCLEO Boards

A XBH - XBD Protocol

Table A.1: Commands of the XBH — XBD Protocol

Requests understood by bootloader		**Responses**	
CMD	**Functionality**	**OK**	**Failed**
XBDpfr	Program Flash Request	XBDpfo	XBDpff
XBDfdr	Flash Download Request	XBDpfo	XBDpff
XBDsar	Start Application Request		
XBDvir	Version Information Request	XBDblo	
XBDtcr	Timing Calibration Request	XBDtco	
XBDtrr	Target Revision Request	XBDtro	
XBDlor	LOopback Request	XBDloo	
Requests understood by AppFramework		**Responses**	
CMD	**Functionality**	**OK**	**Failed**
XBDppr	Program Parameter Request	XBDppo	XBDppf
XBDpdr	Program Download Request	XBDpdo	XBDpdf
XBDurr	Upload Result Request	XBDuro	XBDurf
XBDrdr	Result Data Request	XBDrdo	XBDurf
XBDexr	EXecute Request	XBDexo	XBDexf
XBDccr	Checksum Compute Request	XBDcco	XBDccf
XBDsbr	Switch to Bootloader Request		
XBDvir	Version Information Request	XBDafo	
XBDtcr	Timing Calibration Request	XBDtco	
XBDsur	Stack Usage Request	XBDsuo	
Common Responses			
CMD	**Functionality**		
XBDunk	UNKnown command		
XBDcrc	CRC error		
XBDfdo	– Not Used –		
XBDfdf	– Not Used –		