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1 Introduction

This document guides how to reduce Linux boot time for i.MX8M Nano board.

Note: The same workflow is applied to the entire i.MX8M family, but for each SoC, specific code updates is required.

The objectives of this document are as follows:

• Measurement and evaluation of default boot time
• Bootloader optimizations
• Linux Kernel and User Space optimizations

1.1 Software environment

Linux BSP release 5.10.72-2.2.0 is used in the optimization process. The imx-image-core Yocto image is used during the experiments.

1.2 Hardware setup and equipment

• Development kit NXP i.MX 8MN EVK LPDDR4.
• Micro SD card: SanDisk Ultra 32 GB Micro SDHC I Class 10 was used for the current experiment.
• Micro-USB cable for debug port.
• Logic analyzer with the following minimum requirements for time measurements: Four channels and 10 MS/s. Saleae Logic 8 is used for the current experiment.

2 General description

This section describes an overview of the typical modifications that can be done to achieve shorter boot times.

2.1 Reducing bootloader time

• Remove the boot delay: It saves about two seconds compared to default configuration while requiring minimal changes. It leads to U-Boot skipping the waits for key press stage during boot.
• Implement Falcon Mode: It saves about four seconds compared to default configuration. It enables the Second Program Loader (SPL) – part of U-Boot to load directly the kernel, skipping the full U-Boot.

2.2 Reducing Linux kernel boot time

• Reduce console messages: It saves about three seconds. Add quiet to the Kernel command line.
• Slim down the Kernel by removing drivers and filesystems: By default, the kernel image contains a lot of drivers and filesystems (ex: UBIFS) in order to enable the majority of the functionalities supported for the board. The list of included drivers and filesystems can be trimmed according to your use case.
2.3 Reducing user-space boot time

- **Change running order in initialization Systemd scripts**: It saves about 600 ms. Launch PSPLASH process as soon as possible, taking into account its dependencies.

3 Measurements

The scope of the measurements is considered to be between the board POR (Power-On Reset) and the start of the PSPLASH process.

The setup used for the following measurements is described in the *Boot Time Measurements Methodology* document.

The measured intervals are as follows:

<table>
<thead>
<tr>
<th>Time point</th>
<th>Interval between pulses</th>
<th>Location of the pulse</th>
<th>Boot stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>BootROM</td>
<td>nRST -&gt; before ddr_init()</td>
<td>board/freescale/imx8mn_evk/spl.c/board_init_f()</td>
<td>SPL</td>
</tr>
<tr>
<td>DDR initialization</td>
<td>before ddr_init() -&gt; after ddr_init()</td>
<td>board/freescale/imx8mn_evk/spl.c/board_init_f()</td>
<td></td>
</tr>
<tr>
<td>SPL initialization + Load U-Boot image</td>
<td>after ddr_init() -&gt; before image_entry()</td>
<td>common/spl/spl.c/jump_to_image_no_args()</td>
<td></td>
</tr>
<tr>
<td>U-Boot initializations (init_sequence_f)</td>
<td>before image_entry() -&gt; start init_sequence_r</td>
<td>common/board_r.c/board_init_r()</td>
<td></td>
</tr>
<tr>
<td>U-Boot initializations (init_sequence_r)</td>
<td>start init_sequence_r -&gt; u-boot main_loop</td>
<td>common/main.c</td>
<td>U-BOOT</td>
</tr>
<tr>
<td>Boot sequence</td>
<td>u-boot main_loop -&gt; before load_image</td>
<td>include/configs/imx8mn_evk.h</td>
<td></td>
</tr>
<tr>
<td>Kernel Image Load</td>
<td>before loadimage -&gt; after loadimage</td>
<td>include/configs/imx8mn_evk.h</td>
<td></td>
</tr>
<tr>
<td>Kernel Boot Until PSPLASH Image</td>
<td>after loadimage -&gt; psplash</td>
<td>psplash.c</td>
<td>Kernel</td>
</tr>
</tbody>
</table>

4 Bootloader optimizations

4.1 Default boot mode

*Figure 1* describes the default boot sequence. After power-on or reset, i.MX8M executes the **BootROM** (the primary program loader), stored in its Read Only Memory (ROM). BootROM configures the System-on-Chip (SoC) by performing basic peripheral initializations such as Phase Locked Loops (PLLs), clock configurations, memory initialization (SRAM), then finds a boot device from where it loads a bootloader image, which can include the following component: U-Boot SPL, ATF, U-Boot, and so on.
Because a typical U-Boot image does not fit inside internal SRAM, it was split into two parts: **Secondary Program Loader (SPL)** and **U-Boot proper**.

**SPL** is the first stage of the bootloader, a smaller pre-loader that shares the same sources as U-Boot, but with a minimal set of code that fits into SRAM. SPL is loaded into SRAM. It configures and initializes some peripherals and, most importantly, DRAM. Subsequently, it loads the ATF and U-Boot proper into the DRAM. The final step is to jump to ATF, which will, in turn, jump to U-Boot proper.

**Arm Trusted Firmware (ATF)**, included recently in i.MX8* families, provides a reference trusted code base for the Armv8 architecture. It implements various ARM interface standards, including Power State Coordination Interface (PSCI). The binary is typically included in the bootloader binary. It starts in the early stages of U-Boot. Without ATF, the kernel cannot setup the services which need to be executed in the Secure World environment.

**U-Boot proper** is the second stage bootloader. It offers a flexible way to load and start the Linux Kernel and provides a minimal set of tools to interact with the board’s hardware via a command line interface. It runs from DRAM, initializing additional hardware devices (network, USB, DSI/CSI, etc.). Then, it loads and prepares the device tree (FDT). The main task handled by the U-Boot is the loading and starting of the kernel image itself.

**Linux Kernel** runs from DRAM and takes over the system completely. The U-Boot has no longer control over the system from this point onward.

### 4.2 Falcon mode

Falcon mode is a feature in U-Boot that enables fast booting by allowing SPL to directly start the Linux kernel, skipping the U-Boot loading and initialization completely, with the effect of reducing the time spent in the bootloader.

**Figure 2** shows the Falcon mode booting sequence.

To implement this mode, perform the following actions:

- Activate some specific configurations for Falcon.
- Prepare the Flattened Device Tree (FDT) in advance.
- Configure ATF to jump to Kernel.
- Write the ATF, Kernel image and FDT on SD card in a raw section, outside partitions.
- Modify SPL to load the ATF and the Kernel, then jump to ATF.

### 4.3 Implementation

The next modifications are made on the host computer, where the Yocto environment was installed.

**Note:** On Windows the `dd` command (from Linux) is available by installing MSYS2. It is a collection of GNU/Linux Tools compiled for Windows.
1. Remove the SPL BootROM support from the configuration file.

Location: <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/configs/imx8mn_evk_defconfig

# CONFIG_SPL_BOOTROM_SUPPORT is not set

2. Add support for raw SD read, enable spl export command, add support for legacy Image, and make specific configurations for Falcon mode.

Location: <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/include/configs/imx8mn_evk.h

#define CONFIG_CMD_SPL     1 // enable spl export command
#define CONFIG_SPL_MMC_SUPPORT 1 // for reading from MMC
#define CONFIG_SPL_LEGACY_IMAGE_SUPPORT 1

/* Falcon Mode */
// #define CONFIG_SPL_OS_BOOT   1 // activate Falcon Mode
/* (leave this line commented until you finish all the configurations) */

// RAM FDT address
#define CONFIG_SYS_SPL_ARGS_ADDR 0x43000000

/* Falcon Mode - MMC support */
#define CONFIG_SYS_MMCSD_RAW_MODE_ARGS_SECTOR 0x2FAF080
#define CONFIG_SYS_MMCSD_RAW_MODE_ARGS_SECTORS 0x58
#define CONFIG_SYS_MMCSD_RAW_MODE_KERNEL_SECTOR 0x2FAF0E4

3. Implement the spl_start_uboot() function that returns 0 to indicate that booting U-Boot is not the first choice;

Location: <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/board/freescale/imx8mn_evk/spl.c

#ifdef CONFIG_SPL_OS_BOOT
int spl_start_uboot(void) {
    return 0;
}
#endif

4. Modify the calculation mode of the Kernel load address in the spl_parse_legacy_header() function, in the else statement (when the load includes the header).

Location: <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/common/spl/spl_legacy.c

Replace the following line:

```
spl_image->load_addr = image_get_load(header) - header_size;
```
With this:

```c
spl_image->load_addr = image_get_ep(header) -
    header_size;
```

5. In the `mmc_load_legacy()` function, add the following line after the existing code, to load the AFT.

**Location:** `<yocto_build_dir>/tmp/work/imx8mn_lppddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/common/spl/spl_mmc.c`

```c
count = blk_dread(mmc_get_blk_desc(mmc), sector,
    image_size_sectors, (void *)(ulong)spl_image->load_addr);
/* end of existing code */
unsigned long count1 = blk_dread(mmc_get_blk_desc(mmc),
    0x2FBDAE0, 0x71,
    (void*)(ulong)0x00960000);  //write ATF from SD to RAM
```

6. In the `board_init_r()` function, modify the SPL to jump to ATF (in jump to Linux case).

**Location:** `<yocto_build_dir>/tmp/work/imx8mn_lppddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/common/spl/spl.c`

```c
#ifdef CONFIG_SPL_OS_BOOT
    case IH_OS_LINUX:
        debug("Jumping to Linux
");
        #if defined(CONFIG_SYS_SPL_ARGS_ADDR)
            spl_fixup_fdt((void *)CONFIG_SYS_SPL_ARGS_ADDR);
        #endif
        spl_board_prepare_for_linux();
        typedef void __noreturn (*image_entry_noargs_t)
            (void);
        image_entry_noargs_t image_entry =
            (image_entry_noargs_t)0x00960000;
        image_entry();
    #endif
```

**Note:** When `CONFIG_SPL_OS_BOOT` is defined, SPL calls the `dram_init_banksize()` function which causes an error resulting in a CPU reset. This is happening due to the usage of uninitialized functions, which can be avoided by allocating memory for the `gd->bd` structure before using it, in the `<yocto_build_dir>/tmp/work/imx8mn_lppddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/arch/arm/mach-imx/imx8m/soc.c` source file.

```c
gd->bd = (struct bd_info*)malloc(sizeof(struct bd_info));
```

7. To bring it up in the operational state in which Ethernet MAC can interact with PHY, reset the Ethernet PHY in U-boot SPL or Linux. The following instructions detail how to reset the PHY from U-Boot SPL:
   a. Check at which pin is connected the FEC device. This is described in the associated DTS file of i.MX8MN EVK board.
Located: `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/arch/arm/dts/imx8mn-evk.dts`

According to the board schematics, the reset pin of Ethernet PHY is connected to group 4, pin 22 (marked in red).

b. Declare a macro containing the pair of GPIO group and GPIO pin in the file. Add a macro to use a pad as a GPIO.

Location: `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/common/spl/spl.c`

```c
#define RESET_ETH_GPIO IMX_GPIO_NR(4, 22)
#define USDHC_GPIO_PAD_CTRL (PAD_CTL_HYS | PAD_CTL_DSE1)
```

c. Reset the Ethernet PHY by adding the following lines in the `board_init_r()` function.

Location: `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/common/spl/spl.c`

```c
/* reset eth */
gpio_request(RESET_ETH_GPIO, "reset_eth_gpio");
gpio_direction_output(RESET_ETH_GPIO, 0);
mdelay(1);
gpio_direction_output(RESET_ETH_GPIO, 1);
mdelay(1);
```

8. Before creating a patch, make sure that all the new modifications are correct. Rebuild the U-Boot image using the following `bitbake` commands on the host:

```bash
$ bitbake -f -c configure u-boot-imx
$ bitbake -f -c compile u-boot-imx
$ bitbake u-boot-imx imx-boot
```

9. After the setup is done, create a patch which contains the U-Boot modifications:

```bash
$ git add --all
$ git commit -s
$ git format-patch HEAD~1

Copy the resulting patch to the following location: imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/u-boot/u-boot-imx, then add the name of the patch into the source location identifier in the Yocto recipe for U-Boot (imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/u-boot/u-boot-imx_2021.04.bb):

```
SRC_URI = "... \n    file://<patch_name>.patch \n"
```

To check that the patch works after the modifications, apply the following commands. Then, the files should contain the latest changes.

```
$ bitbake -f -c cleansstate u-boot-imx
$ bitbake u-boot-imx imx-boot
```

10. Generate the bootloader image with SPL only.

Create a new target for building the new image, in the `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/imx-boot/<specified_git_folder>/git/iMX8M/soc.mak` file.

If the board is configured with HDMI, add these lines in `ifeq((HDMI),yes)` condition.

```
flash_evk_falcon: $(MKIMG) signed_hdmi_imx8m.bin u-boot-spl-ddr.bin
    ./mkimage_imx8 -fit -signed_hdmi
    signed_hdmi_imx8m.bin -loader u-boot-spl-ddr.bin
    $(SPL_LOAD_ADDR) -out $(OUTIMG)
```

Else, make a new target that will not include HDMI and implement it:

```
flash_evk_falcon: flash_evk_falcon_no_hdmi

flash_evk_falcon no hdmi: $(MKIMG) u-boot-spl-ddr.bin
    ./mkimage_imx8 -version $(VERSION) -loader u-boot-spl-ddr.bin
    $(SPL_LOAD_ADDR) -out $(OUTIMG)
```

To regenerate `flash.bin` (imx-boot image), run `make SOC=iMX8MN flash_evk_falcon`.

11. Create a patch that will include the modifications above:

```
$ git add soc.mak
$ git commit -s
$ git format-patch HEAD~1
```

Copy the resulted patch to `~/imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/imx-mkimage/files`, and then add the name of the patch into the source location identifier in the Yocto recipe for `imx-mkimage` (~/*imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/imx-mkimage/imx-mkimage_git.inc):

```
SRC_URI = "... \n    file://<patch_name>.patch \n"
```
To check that the patch works after the modifications, apply the following commands.
Then, the file should contain the latest changes:

```bash
$ bitbake -f -c cleansstate imx-boot
$ bitbake imx-boot
$ make SOC=iMX8MN flash_evk_falcon
```

12. Write the bootloader image on SD card.

**Note:** Storage location may vary. Adjust the `of` parameter to point to the SD card location.

```bash
dd if=flash.bin of=/dev/sdb bs=1k seek=32 conv=fsync
```

13. Configure the ATF to jump to Kernel image.

In the `bl31_early_platform_setup2()` function, set the program counter member of `bl33_image_ep_info` structure to kernel address and give the address of the FDT as an argument.

Location: `<yocto_build_dir>/tmp/work/cortexa53-crypto-mx8mn-poky-linux/imx-atf/<specified_git_folder>/git/plat/imx/imx8m/imx8mn/imx8mn_bl31_setup.c`

```c
//bl33_image_ep_info.pc = PLAT_NS_IMAGE_OFFSET;
bl33_image_ep_info.pc = 0x40400000; // RAM kernel address
bl33_image_ep_info.spsr = get_spsr_for_bl33_entry();
// RAM FDT address
bl33_image_ep_info.args.arg0 = (u_register_t)0x43000000;
bl33_image_ep_info.args.arg1 = 0U;
bl33_image_ep_info.args.arg2 = 0U;
bl33_image_ep_info.args.arg3 = 0U;
SET_SECURITY_STATE(bl33_image_ep_info.h.attr, NON_SECURE);
```

14. Recompile the ATF sources.

Before making a patch, make sure that the sources compile.

```bash
$ bitbake imx-atf
```

You can find the ATF binary (`bl31.bin`) in the `build/imx8mn/release` directory.

Create a patch which includes the new modifications.

```bash
$ git add plat/imx8m/imx8mn/bl33_setup.c
$ git commit -s
$ git format-patch HEAD~1
```

Copy the resulting patch to the following location: `imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/imx-atf/files`, append a new recipe to the existing one (create `imx-atf_2.4.bbappend file`), and add these lines in `imx-yocto-bsp/sources/meta-imx/meta-bsp/recipes-bsp/imx-atf/imx-atf_2.4.bbappend`.

```bash
FILESEXTRAPATHS_prepend := "${THISDIR}/files:"
SRC_URI += "file://0001-jump-to-kernel.patch \
"
```

To check that the patch works after the modifications, apply the following commands.
Then, the file should contain the new changes:

```bash
$ bitbake -f -c cleansstate imx-atf
```
$ bitbake imx-atf

**Note:** To build the ATF manually, use the Yocto meta-toolchain.

$ bitbake meta-toolchain
$ cd imx-yocto-bsp/build-wayland/tmp/deploy/sdk
$ ./fsl-imx-wayland-glibc-x86_64-meta-toolchain-cortexa53-crypto-imx8mn-lpddr4-evk-toolchain-5.10-hardknott.sh
$ source /opt/fsl-imx-wayland/5.10-hardknott/environment-setup-cortexa53-crypto-poky-linux; unset LDFLAGS
$ cd <yocto_build_dir>/tmp/work/cortexa53-crypto-mx8mn-poky-linux/imx-atf/<specified_git_folder>/git
$ make PLAT=imx8mn bl31

15. Write the ATF on SD card.

**Note:** Storage location may vary. To point to the SD card location, adjust the `of` parameter.

    dd if=b31.bin of=/dev/sdb bs=512 seek=50060000 conv=fsync

16. Choose the entry point and load addresses of the Kernel image.

Before booting the kernel, U-Boot relocates the kernel image to an address which is multiple of 2 MB. To bypass this relocation, the entry point address has to be set in advance using the same criteria (address has to be a multiple of 2 MB). The address from where the kernel will be executed is 0x40400000. Considering that the uImage has a 64-byte header, the load address will be 0x403fffc0.

17. Build the Kernel legacy uImage file from Image.

uImage is a special image file that adds a 64-byte header before Image, where loader information is specified (load address, entry point, OS type, and so on).

a. Change the directory where the Kernel image is deployed after build.

    $ cd <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/imx-imx/<specified_git_folder>/build/arch/arm64/boot

b. Generate ulimage using U-Boot’s mkimage command:

    $ mkimage -A arm -O linux -T kernel -C none -a 0x403FFC0 -e 0x40400000 -n "Linux kernel" -d Image ulImage

    Image Name: Linux kernel
    Created: Wed May 4 11:02:52 2022
    Image Type: ARM Linux Kernel Image (uncompressed)
    Data Size: 30118400 Bytes = 29412.50 KiB = 28.72 MiB
    Load Address: 0x403FFC0
    Entry Point: 0x40400000

Where:

- **A [architecture]**: To set architecture.
- **O [os]**: To set operating system.
- **T [image type]**: To set image type.
- **C [compression type]**: To set compression type.
- **n [image name]**: To set image name to `image name`.
- **d [image data file]**: To use image data from `image data file`.
- **a [load address]**: To set load address with a hex number.
- **e [entry point]**: To set entry point with a hex number.
18. Prepare the Flattened Device Tree and write it on SD card. When booting in Falcon Mode, an important step is to prepare the device tree. Usually, U-Boot does FDT fixups when booting Linux. It means that to the initial device tree, U-Boot adds Kernel arguments. These arguments can be found in one of the configuration files:

```
<yocto_build_dir>/tmp/work/imx8mn_lpdrr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/include/configs/imx8mn_evk.h
```

under the name `bootargs`, where the console parameters are specified and which tells the kernel where to find the root file system.

To skip U-Boot, the FDT has to be prepared in advance by using `spl export` command. It should be called under the normal boot. The command is equivalent to go through `bootm` until device tree fixup is done. The device tree in memory is the one needed for falcon mode. This image has to be saved to SD at the location pointed by macro `CONFIG_SYS_MMCSD_RAW_MODE_ARGS_SECTOR`, with maximum size specified by macro `CONFIG_SYS_MMCSD_RAW_MODE_ARGS_SECTORS`.

Steps to prepare the FDT:

- Boot the board into U-Boot and stop it right before entering in autoboot sequence.
- Load the FDT into RAM:

```
u-boot=> run loadfdt
41608 bytes read in 2 ms (19.8 MiB/s)
```

- Load the Kernel ulmage into RAM:

```
u-boot=> fatload mmc ${mmcdev}:${mmcpart} ${loadaddr} uImage
30118464 bytes read in 320 ms (89.8 MiB/s)
```

- Write the Kernel Image to SDHC at the specified offset sector;

```
u-boot=> mmc write ${loadaddr} 0x2FAF0E4 0xe5c9
MMC write: dev # 1, block # 50000100, count 58825 ... 58825 blocks written: OK
```

- Prepare FDT

```
u-boot=> spl export fdt ${loadaddr} - ${fdt_addr_r}
## Booting kernel from Legacy Image at 40400000 ...
  Image Name:   Linux kernel
  Created:      2022-04-08 13:08:28 UTC
  Image Type:   ARM Linux Kernel Image (uncompressed)
  Data Size:    30118400 Bytes = 28.7 MiB
  Load Address: 403fffc0
  Entry Point:  40400000
  Verifying Checksum ... OK
## Flattened Device Tree blob at 0x43000000
  Using Device Tree in place at 0000000043000000, end 000000004300d287
  subcommand not supported
  subcommand not supported
  Using Device Tree in place at 0000000043000000, end 0000000043010287
  Argument image is now in RAM: 0x0000000043000000
```
• Write the prepared FDT to SD card.

```
u-boot=> mmc write 0x43000000 0x2FAF080 0x58
```

**Note:**
*It is possible to rewrite the FDT on SD card. To save it locally on PC, use the following command:*

```
dd if=/dev/sdb of=imx8mn-evk.dtb bs=512 skip=50000000 count=88 conv=fsync
```

**Note:** Storage location may vary. To point to the SD card location, adjust the `of` parameter.

After the modifications, the resulted SD card looks like Figure 3.

<table>
<thead>
<tr>
<th>8MB</th>
<th>83MB</th>
<th>1.5GB</th>
<th>45KB</th>
<th>30MB</th>
<th>58KB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0</td>
<td>0x0</td>
<td>0x30000</td>
<td>0x02FAF080</td>
<td>0x02FAF0E4</td>
<td>0x02FAF0E4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0x3B9ACA0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3. SD card structure**

19. Uncomment the definition of `CONFIG_SPL_OS_BOOT` from Step 2.

20. Recompile and write the bootloader on SD card.

```
$ bitbake -f -c configure u-boot-imx
$ bitbake -f -c compile u-boot-imx
$ cd <yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/
    u-boot-imx/<specified_git_folder>/git/
$ make SOC=IMX8MN flash_evk_falcon
```

Write the U-Boot image on SD card.

**Note:** Storage location may vary. To point to the SD card location, adjust the `of` parameter.

```
dd if=flash.bin of=/dev/sdb bs=1k seek=32 conv=fsync
```

### 4.4 Improve raw MMC read performance in SPL

After implementing Falcon mode, it can be observed that the time spent in SPL increased significantly. It is due to the fact that the kernel image is loaded into memory slowly (large size ~30 MB). To increase the speed transfer in SPL, add support for high speed (UHS/SD):

**Location:** `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-
boot-imx/<specified_git_folder>/git/configs/imx8mn_evk_defconfig`

```
CONFIG_SPL_MMC_UHS_SUPPORT=y
CONFIG_SPL_MMC_IO_VOLTAGE=y
```

**Note:** You can see all the configurations available in `<yocto_build_dir>/
tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/
<specified_git_folder>/git/Kconfig file.`
Recompile the bootloader with these modifications and write it as in Step 20.

5 Kernel space optimizations

5.1 Adding quiet

To reduce the Kernel time by about a half, add quiet argument in Kernel bootargs. It suppresses some messages during the Linux start-up sequence.

The device tree have to be regenerated with the new bootargs, using the spl export command.

1. Reboot in default boot mode.
   a. Comment the definition of CONFIG_SPL_OS_BOOT from `<yocto_build_dir>/tmp/work/imx8mn_lpddr4_evk-poky-linux/u-boot-imx/<specified_git_folder>/git/include/configs/imx8mn_evk.h`
   b. Recompile & rewrite the bootloader as in Step 20.
2. Enter U-Boot and edit the bootargs parameter by adding quiet.

   
   ```
   u-boot=> edit bootargs
   edit: console=ttymxc1,115200 root=/dev/mmcblk1p2 rootwait rw quiet
   u-boot=> saveenv
   Saving Environment to MMC... Writing to MMC(1)... OK
   ```
3. Regenerate and load the device tree to SDHC as in Step 18.
4. Reenter in Falcon mode following Step 19 and Step 20.

5.2 Removing unnecessary drivers and file systems

Depending on your use case, you can slim down the Kernel by removing unnecessary drivers and file systems. You can analyze Kernel functions during boot with bootgraph, a Kernel feature that allows to graph what happens in Kernel during initializations.

To create a bootgraph, perform the following steps:

1. Add initcall_debug to Kernel bootargs.
   a. Reboot in default boot mode as in Step 1.
   b. Enter U-Boot and edit the bootargs parameter by adding initcall_debug.

   ```
   u-boot=> edit bootargs
   edit: console=ttymxc1,115200 root=/dev/mmcblk1p2 rootwait rw quiet initcall_debug
   u-boot=> saveenv
   Saving Environment to MMC... Writing to MMC(1)... OK
   ```
2. Regenerate and load the device tree to SDHC as in Step 18.
3. Reenter in Falcon Mode following the Step 19 and Step 20.
4. Boot the board and get the Kernel log.

   ```
   root@imx8mn-lpddr4-evk:~# dmesg > boot.log
   ```
5. Go back on the host and create the graph using the following commands:

   ```
   $ cd <yocto_build_dir>/tmp/work-shared/imx8mn-lpddr4-evk/kernel-source/scripts
   ```
$ ./bootgraph.pl boot.log > boot.svg

You will obtain something like this and can analyze how the Kernel boot time is used.

![Function timeline during kernel boot](image)

Figure 4. Function timeline during kernel boot

6. To disable a driver or a feature, update the Kernel configuration.
   For example, we disabled the debug from Kernel (that reduce the size of the image) and the UBI file system.
   a. In `sources/meta-imx/meta-bsp/recipes-kernel/linux/files`, create a fragment configuration file `frag.cfg` in which you include these lines:
      ```
      # CONFIG_UBIFS_FS is not set
      # CONFIG_DEBUG_KERNEL is not set
      ```
   b. For this to be merged with the default configuration file, we have to append a new recipe. Create `linux-imx_5.10.bbappend` in `sources/meta-imx/meta-bsp/recipes-kernel/linux` and add these lines:
      ```
      FILESEXTRAPATHS_prepend := "$(THISDIR)/files:"
      SRC_URI += "file://frag.cfg \
      "
      DELTA_KERNEL_DEFCONFIG = "frag.cfg"
      ```
   c. Recompile the Kernel with the new configuration, convert into uImage with `mkimage` and write it to SD.
      ```
      $ bitbake -c cleansstate virtual/kernel
      $ bitbake -f -c compile virtual/kernel
      ```
   d. Convert the Kernel image into uImage as in Step 17.
   e. Write the uImage Kernel to SD card.

   **Note:** Storage location may vary. To point to the SD card location, adjust the `of` parameter.

   ```
   dd if=uImage of=/dev/sdb bs=512 seek=5000100 conv=fsync
   ```

6. User space optimizations

The easiest way to reduce the time spent in user-space is to reorder the sequence in which applications are run. To start the `psplash` service earlier, change the dependencies with which `Systemd` operates.

On board, open `/lib/systemd/system/psplash-start.service` file and change the unit dependencies by making `psplash` started before `local-fs-pre.target`.

```
[Unit]
Description=Start Psplash Boot Screen
#Wants=systemd-vconsole-setup.service
#After=systemd-vconsole-setup.service systemd-udevd.service
Before=local-fs-pre.target
DefaultDependencies=no
```
If the command system-analyze is called with blame argument, Systemd also provides a utility called systemd-analyze which prints the services and their starting time.

$ systemd-analyze blame

To disable a service, you can use the systemctl disable command. Some services (especially the ones provided by systemd) might need the systemctl mask command to disable them. However, take care when disabling services since the system may depend on them to operate properly.

7 Results

Table 2. Initial Linux boot time measurements

<table>
<thead>
<tr>
<th>No.</th>
<th>BOOTROM</th>
<th>DDR initialization</th>
<th>SPL initializations + Load U-Boot image</th>
<th>U-Boot initializations (init_sequence_f)</th>
<th>U-Boot initializations (init_sequence_r)</th>
<th>Boot sequence</th>
<th>Kernel image load</th>
<th>Kernel boot until PSPLASH image</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>260</td>
<td>253</td>
<td>285</td>
<td>594</td>
<td>906</td>
<td>3651</td>
<td>329</td>
<td>5768</td>
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<td>328</td>
<td>5975</td>
<td>12310</td>
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</tbody>
</table>

Average time (ms) 805 5579 5883 12264

Table 3. Optimized Linux boot time measurements

<table>
<thead>
<tr>
<th>No.</th>
<th>BOOTROM</th>
<th>DDR initialization</th>
<th>SPL initializations</th>
<th>Kernel Image Load</th>
<th>Kernel Boot Until PSPLASH Image</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
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<td>253</td>
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<td>461</td>
<td>2594</td>
<td>3692</td>
</tr>
</tbody>
</table>

Average time (ms) 1099 2734 3832

8 References

- i.MX 8M Nano Applications Processor Reference Manual (document IMX8MNRM)
- Presentation: Understanding U-Boot Falcon Mode, Michael Opdenacker, June 3rd 2021
- U-Boot Source Code - Falcon README
# Revision history

<table>
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<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
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<tr>
<td>0</td>
<td>18 August 2022</td>
<td>Initial release</td>
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