Update on filesystems for flash storage

Michael Opdenacker.
Free Electrons
http://free-electrons.com/

About this document

-
- Documents updates can be found or described on http://free-electrons.com/docs/flash-filesystems/

Contents

The MTD subsystem

Linux filesystem interface

MTD “User” modules

UBI

jffs2

Char device

Block device

yaffs2

Read-only block device

Flash Translation Layers
for block device emulation
Caution: patented algorithms!

FTL

NFTL

INFTL

MTD Chip drivers

CFI flash

RAM chips

NAND flash

DiskOnChip flash

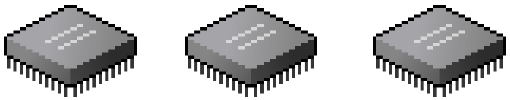
ROM chips

Block device

Virtual memory

Virtual devices appearing as
MTD devices

Memory devices hardware



MTD - How to use

Creating the device nodes

Char device files

- `mknod /dev/mtd0 c 90 0`
- `mknod /dev/mtd1 c 90 2` (Caution: `2` and not `1`)
- `mknod /dev/mtd2 c 90 4` (Caution: `4` and not `2`)

Block device files

- `mknod /dev/mtdblock0 b 31 0`
- `mknod /dev/mtdblock1 b 31 2`
- `mknod /dev/mtdblock2 b 31 4`

Existing solutions

For the last years, only 2 filesystem choices for flash storage

jffs2

- Wear leveling, ECC
- Power down resistant
- Compression
- Huge mount times
- Rather big memory usage
- Mainstream support

yaffs2

- Wear leveling, ECC
- Power down resistant
- No compression
- Very quick mount time
- Available as a Linux patch.

2 solutions, but far from being perfect!

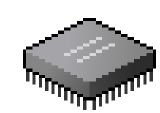
jffs2

- Today's standard filesystem for MTD flash
- Nice features:
  - On the fly compression. Saves storage space and reduces I/O.
  - Power-down reliable.
  - Implements wear-leveling
- Drawbacks: doesn't scale well
  - Mount time depending on filesystem size:
    the kernel has to scan the whole filesystem at mount time, to read which block belongs to each file.
  - Keeping this information in RAM is memory hungry too.

Standard file API

JFFS2 filesystem

MTD driver



Flash chip

New jffs2 features

- `CONFIG_JFFS2_SUMMARY`
  Reduces boot time by storing summary information.
- New jffs2 compression options:
  - Now supports lzo compression, and not only zlib (and also the rtime and rubin compressors)
  - Can try all compressors and keep the one giving the best results
  - Can also give preference to lzo, to the expense of size, because lzo has the fastest decompression times.

jffs2 - How to use

- Compile mtd-tools if needed:
  `git-clone git://git.infradead.org/mtd-utils.git`
- Erase and format a partition with jffs2:
  `flash_eraseall -j /dev/mtd2`
- Mount the partition:
  `mount -t jffs2 /dev/mtdblock2 /mnt/flash`
- Fill the contents by writing
- Or, use an image:
  `nandwrite -p /dev/mtd2 rootfs.jffs2`

Mounting a jffs2 image

Useful to create or edit `jffs2` images on your GNU / Linux PC!

- Mounting an MTD device as a loop device is a bit complex task. Here's an example for `jffs2`, for your reference:

```
losetup /dev/loop0 root.jffs2
mknod /dev/mtdblock0 b 31 0                    (if not done yet)
mkdir /mnt/jffs2            (example mount point, if not done yet)
modprobe block2mtd
echo "/dev/loop0" > /sys/module/block2mtd/parameters/block2mtd
mount -t jffs2 /dev/mtdblock0 /mnt/jffs2
```

yaffs2

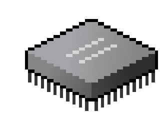
http://www.yaffs.net/

- Supports both NAND and NOR flash
- No compression
- Wear leveling, ECC, power failure resistant
- Fast boot time
- Code available separately through CVS
  (Dual GPL / Proprietary license
  for non Linux operating systems)

Standard file API

YAFFS2 filesystem

MTD driver



Flash chip

yaffs2 - How to use

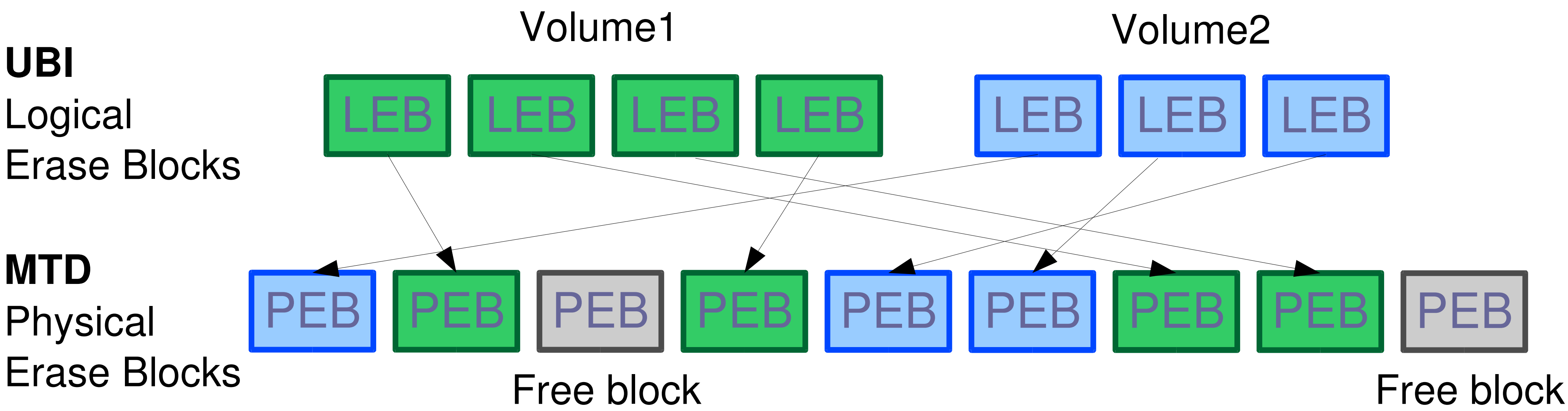
- Erase a partition:
  `flash_eraseall /dev/mtd2`
- Format the partition:
  `sleep` (any command can do!)
- Mount the partition:
  `mount -t yaffs2 /dev/mtdblock2 /mnt/flash`

UBI (1)

Unsorted Block Images

- http://www.linux-mtd.infradead.org/doc/ubi.html
- Volume management system on top of MTD devices.
- Allows to create multiple logical volumes
  and spread writes across all physical blocks.
- Takes care of managing the erase blocks and wear leveling. Makes filesystem easier to implement.

UBI (2)


Volume1
Volume2
UBI
Logical
Erase Blocks
LEB
LEB
LEB
LEB
LEB
LEB
LEB
MTD
Physical
Erase Blocks
PEB
PEB
PEB
PEB
PEB
PEB
PEB
PEB
PEB
Free block
Free block

UBI - How to use (1)

- First, erase your partition
  `flash_eraseall /dev/mtd1`
- First, format your partition:
  `ubiformat /dev/mtd1 -s 512`
  (possible to set an initial erase counter value)
  See http://www.linux-mtd.infradead.org/faq/ubi.html if you face problems
- Need to create a `/dev/ubi_crtl device` (if you don't have udev)
  Major and minor number allocated in the kernel. Find these numbers in
  `/sys/class/misc/ubi_ctrl/dev` (e.g.: `10:63`)
  Or run `ubinfo`:

```
UBI version:                    1
Count of UBI devices:           1
UBI control device major/minor: 10:63
Present UBI devices:            ubi0
```

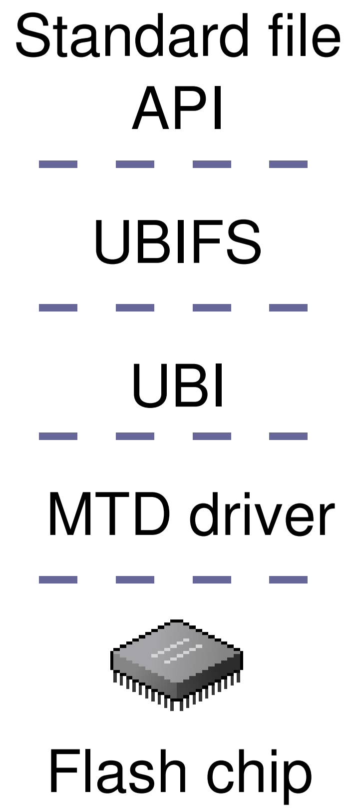
UBI - How to use (2)

- Attach UBI to one (of several) of the MTD partitions:
  `ubiattach /dev/ubi_ctrl -m 1`
- Find the major and minor numbers used by UBI:
  `cat /sys/class/ubi/ubi0/dev` (e.g. `253:0`)
- Create the UBI device file:
  `mknod /dev/ubi0 c 253 0`

UBIFS

http://www.linux-mtd.infradead.org/doc/ubifs.html

- The next generation of the jffs2 filesystem, from the same linux-mtd developers.
- Available in Linux 2.6.27
- Works on top of UBI volumes



UBIFS - How to use

Creating

- `ubimkvol /dev/ubi0 -N test -s 116MiB`
  or `ubimkvol /dev/ubi0 -N test -m` (max available size)
- `mount -t ubifs ubi0:test /mnt/flash`

Deleting

- `umount /mnt/flash`
- `ubirmvol /dev/ubi0 -N test`
- Detach the MTD partition:
  `ubidetach /dev/ubi_ctrl -m 1`

Suitability for very small partitions

8M MTD partition

- jffs2 fits 13 MB of files
  But probably doesn't leave enough free blocks
- UBI consumes 0.9 MB
  ubifs fits 6.6 MB of files

4M MTD partition

- jffs2 fits 5.1 MB of files
- UBI consumes 0.8 MB
  ubifs fits only 1.6 MB of files!

Bigger sizes: UBI overhead can be neglected:
32 MB: consumes 1.2 MB
128 MB: consumes 3.6 MB

LogFS

http://logfs.org/logfs/

- Also developed as a replacement for jffs2
- Expect very fast mount times!
- Didn't seem to be ready when we ran our benchmarks.
- Now ready for experimental tests with recent kernels: http://logfs.org/git?p=logfs;a=summary

SquashFS

http://squashfs.sourceforge.net/

- Filesystem for block storage!
  Doesn't support the MTD API.
- But read-only! No problem with managing erase blocks and wear-leveling. So, it's fine to use it with the `mtdblock` driver.
- You can use it for the read-only sections in your filesystem.

SquashFS - How to use

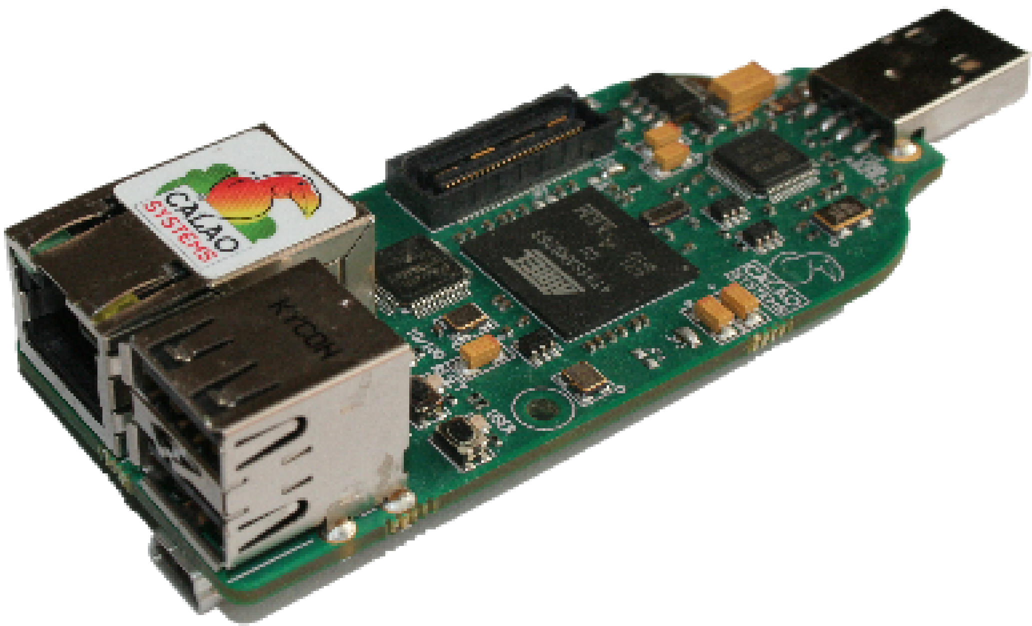
Very simple!

- On your workstation, create your filesystem image (example: `120m/` directory in our benchmarks)
  `mksquashfs 120m 120m.sqfs`
- Erase your flash partition:
  `flash_eraseall /dev/mtd2`
- Make your filesystem image available to your device (NFS, copy, etc.) and flash your partition:
  `dd if=120m.sqfs of=/dev/mtdblock2`
- Mount your filesystem:
  `mount -t squashfs /dev/mtdblock2 /mnt/flash`

Benchmarks

Test hardware

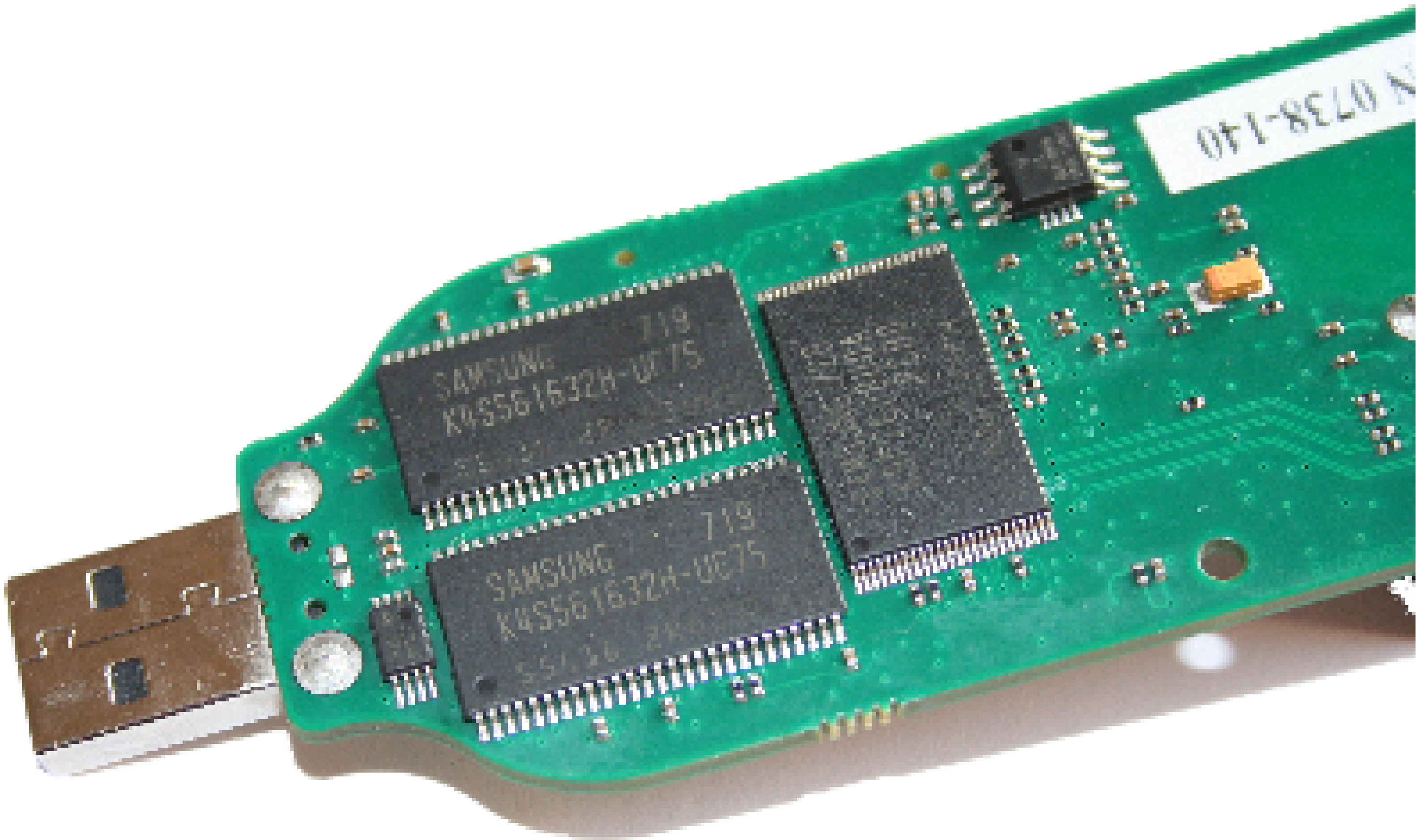
Calao Systems USB-A9263



Supported by Linux 2.6.27!

- AT91SAM9263 ARM CPU
- 64 MB RAM
  256 MB flash
- 2 USB 2.0 host
  1 USB device
- 100 Mbit Ethernet port
- Powered by USB!
  Serial and JTAG through this USB port.
- Multiple extension boards.
- 162 EUR

NAND device: Manufacturer ID: 0xec, Chip ID: 0xda
(Samsung NAND 256MiB 3,3V 8-bit)



Samsung's reference: K4S561632H-UC75

Benchmark overview

Compared filesystems:

- jffs2, default options
- jffs2, lzo compression only
- yaffs2
- ubifs, default options
- ubifs, no compression
- squashfs

Different MTD partitions

- 8M
- 32M
- 120M

Corresponding to most embedded device scenarios.

Partitions filled at about 85%

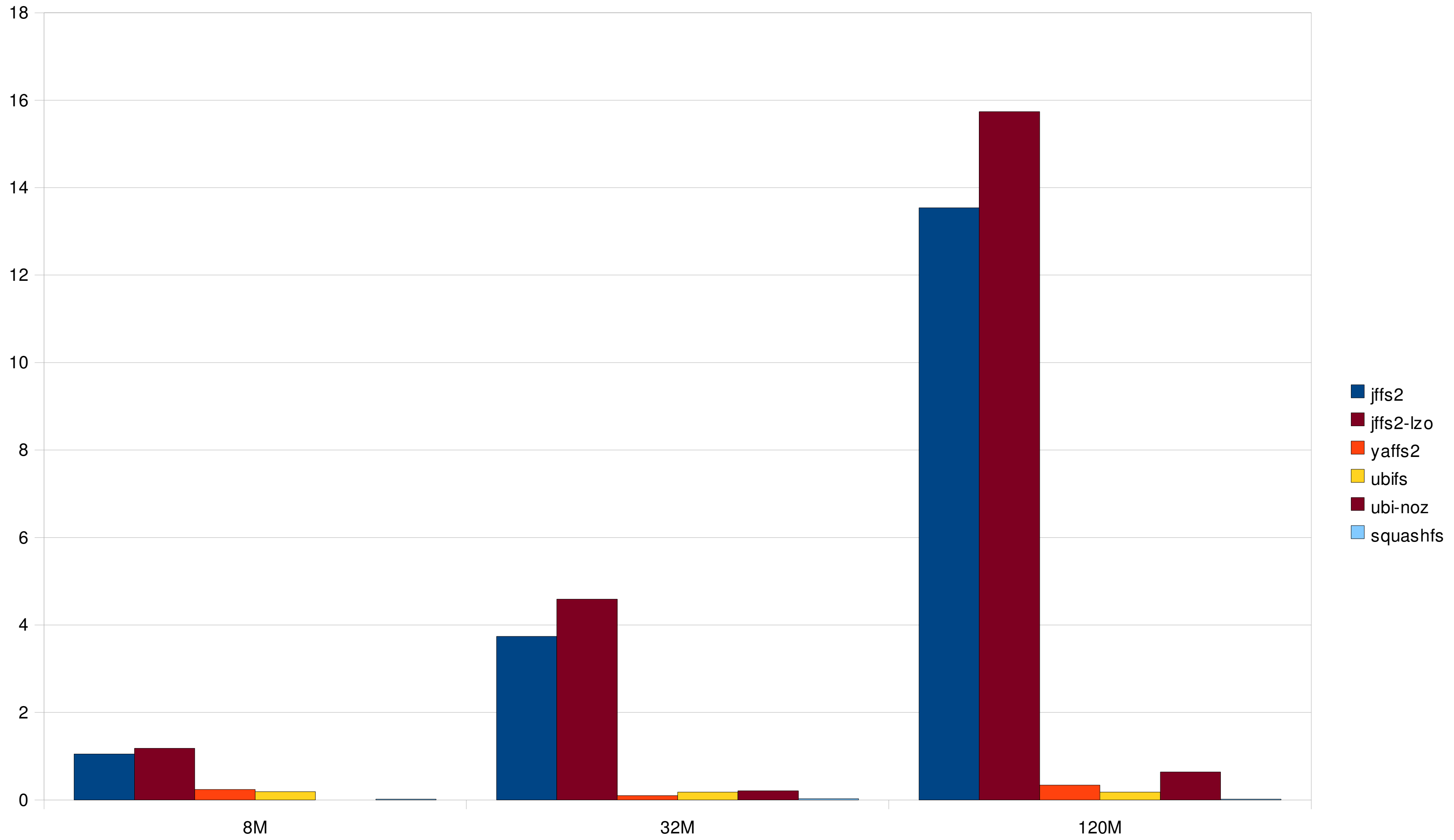
All tested with Linux 2.6.27.

Read and mounting experiments

- Mounting an arm Linux root filesystem, taken from the OpenMoko project.
- Advantages: mainly contains compressible files (executables and shared libraries).
- Represents a very important scenario: booting on a filesystem in flash. Mounting and file access time are major components of system boot time.

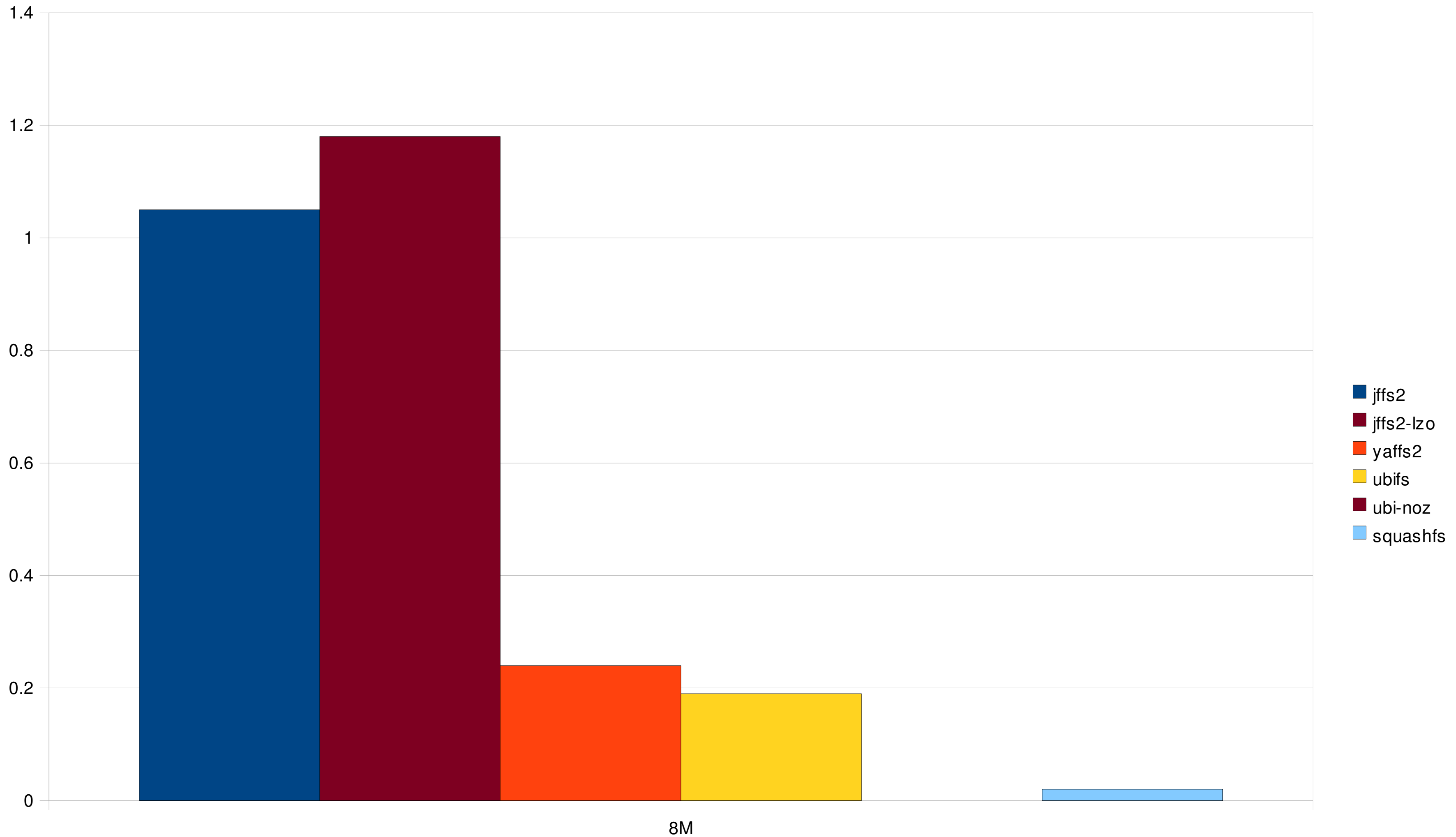
Mount time (seconds)

ubifs-noz / 8M: doesn't fit



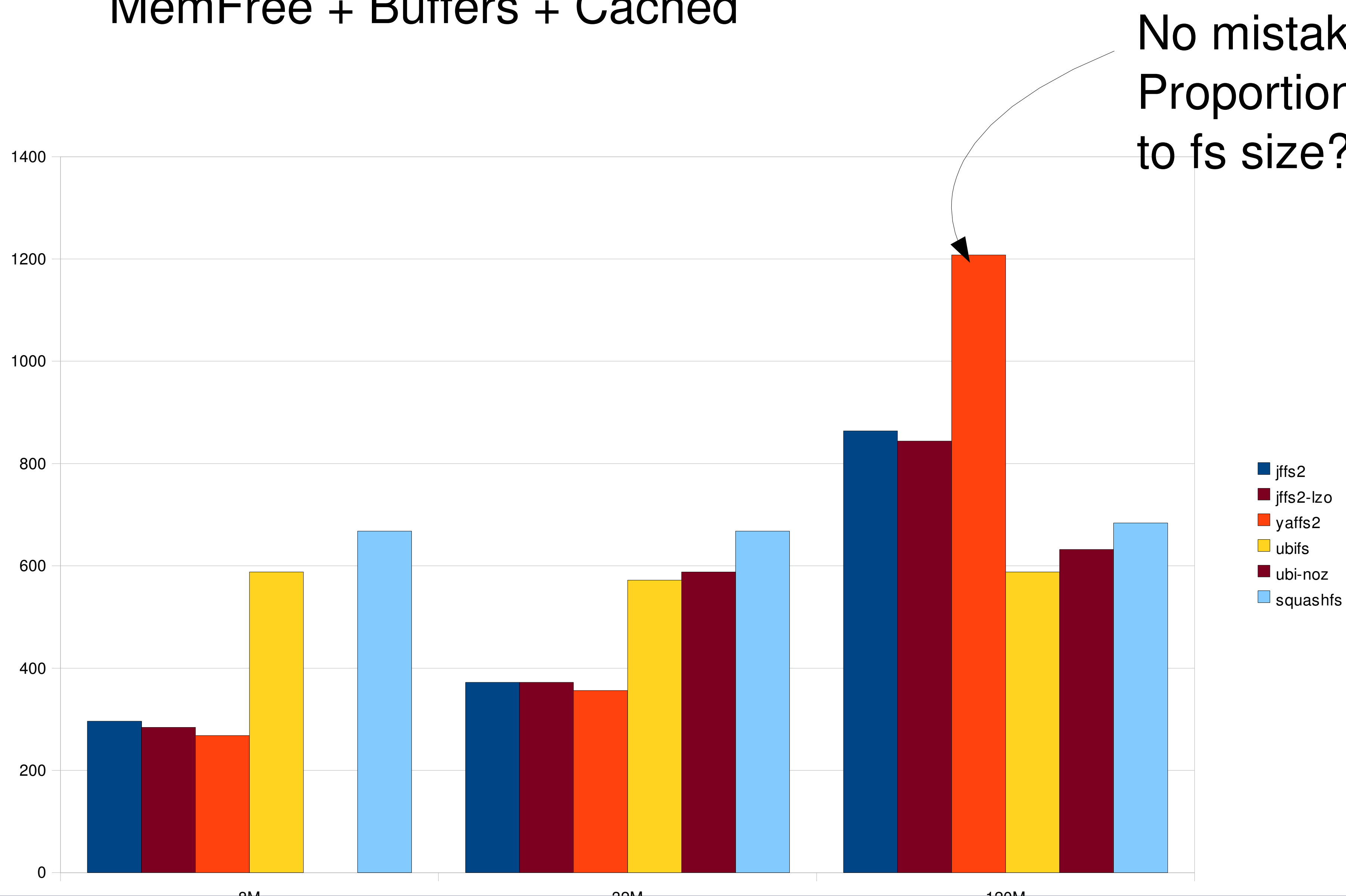
Zoom - Mount time (seconds) - 8M

ubifs-noz / 8M: doesn't fit



Memory consumption after mounting (KB)

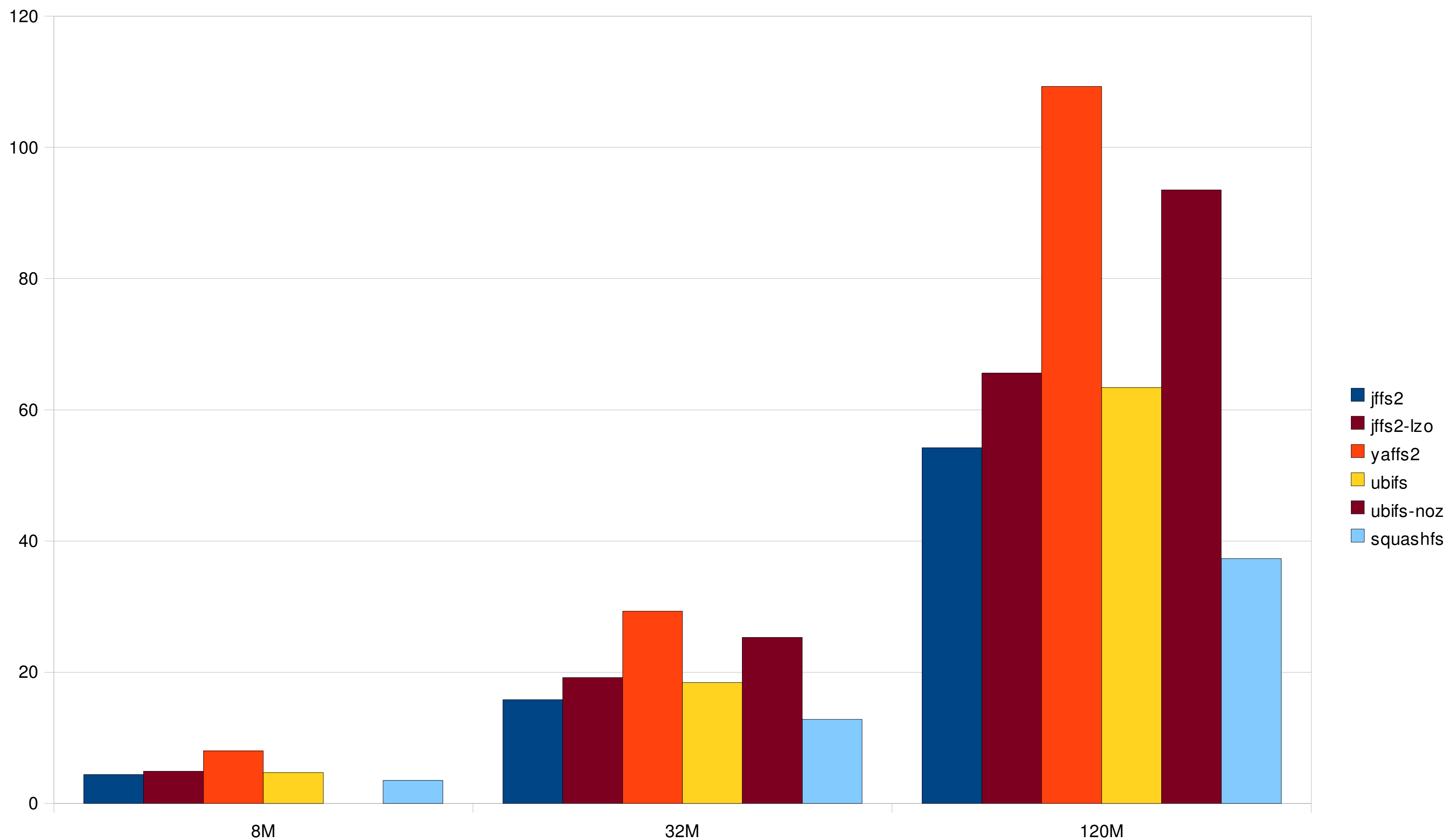
Free memory measured with /proc/meminfo:
MemFree + Buffers + Cached



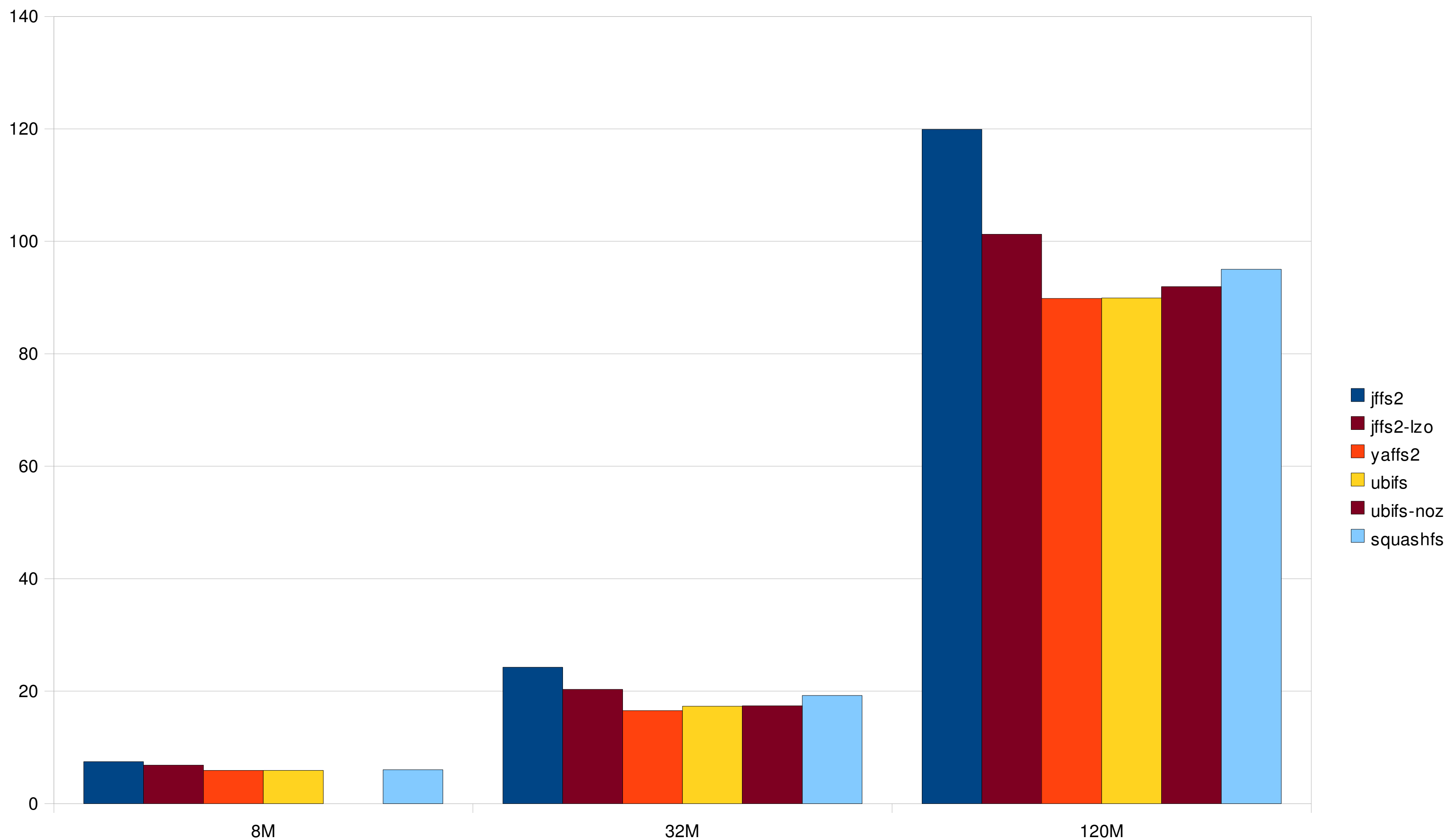
Used space (MB)

Measured with `df`

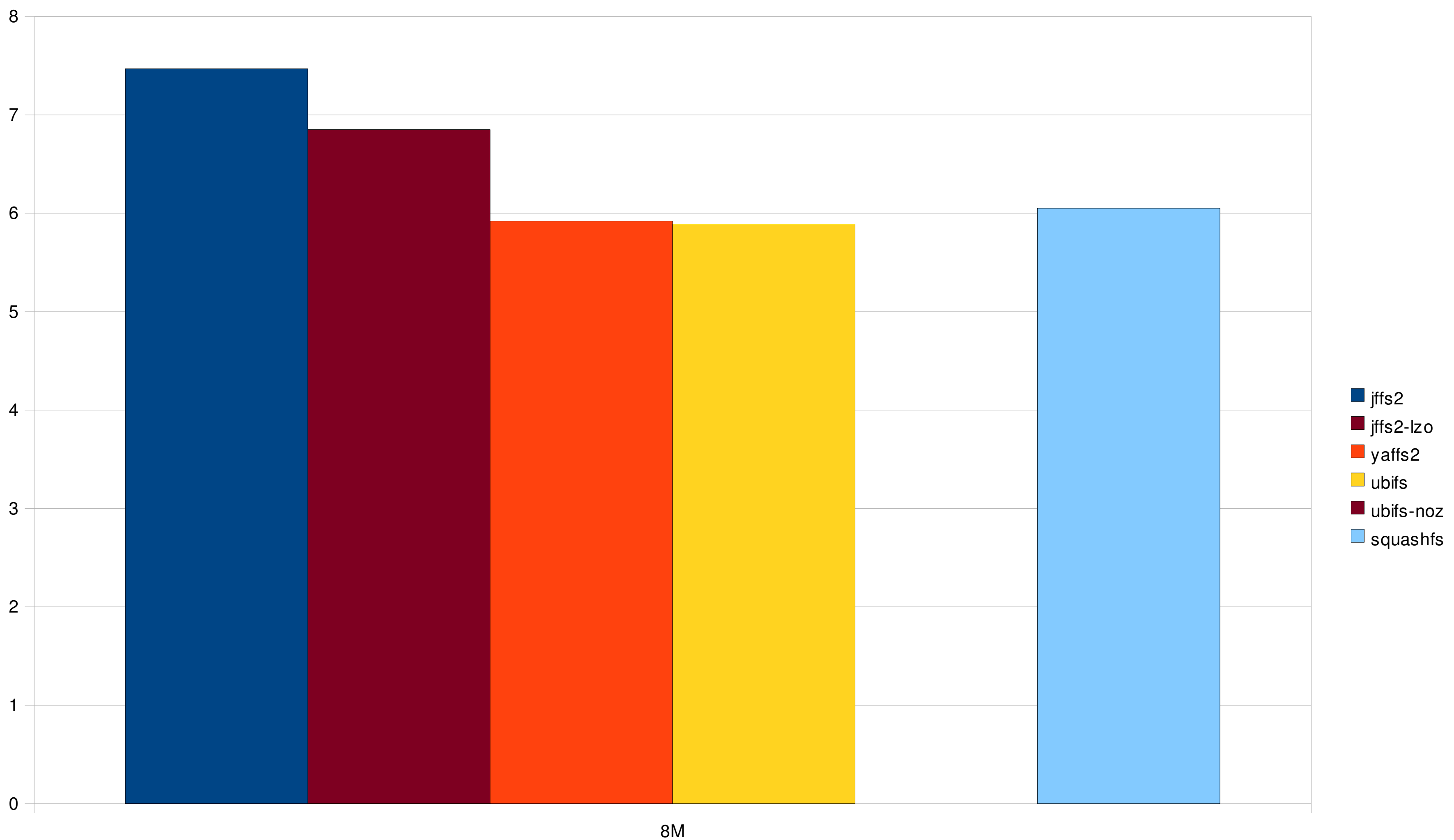
Add some space for UBIFS!
1 MB for 8 MB



Read time (seconds)

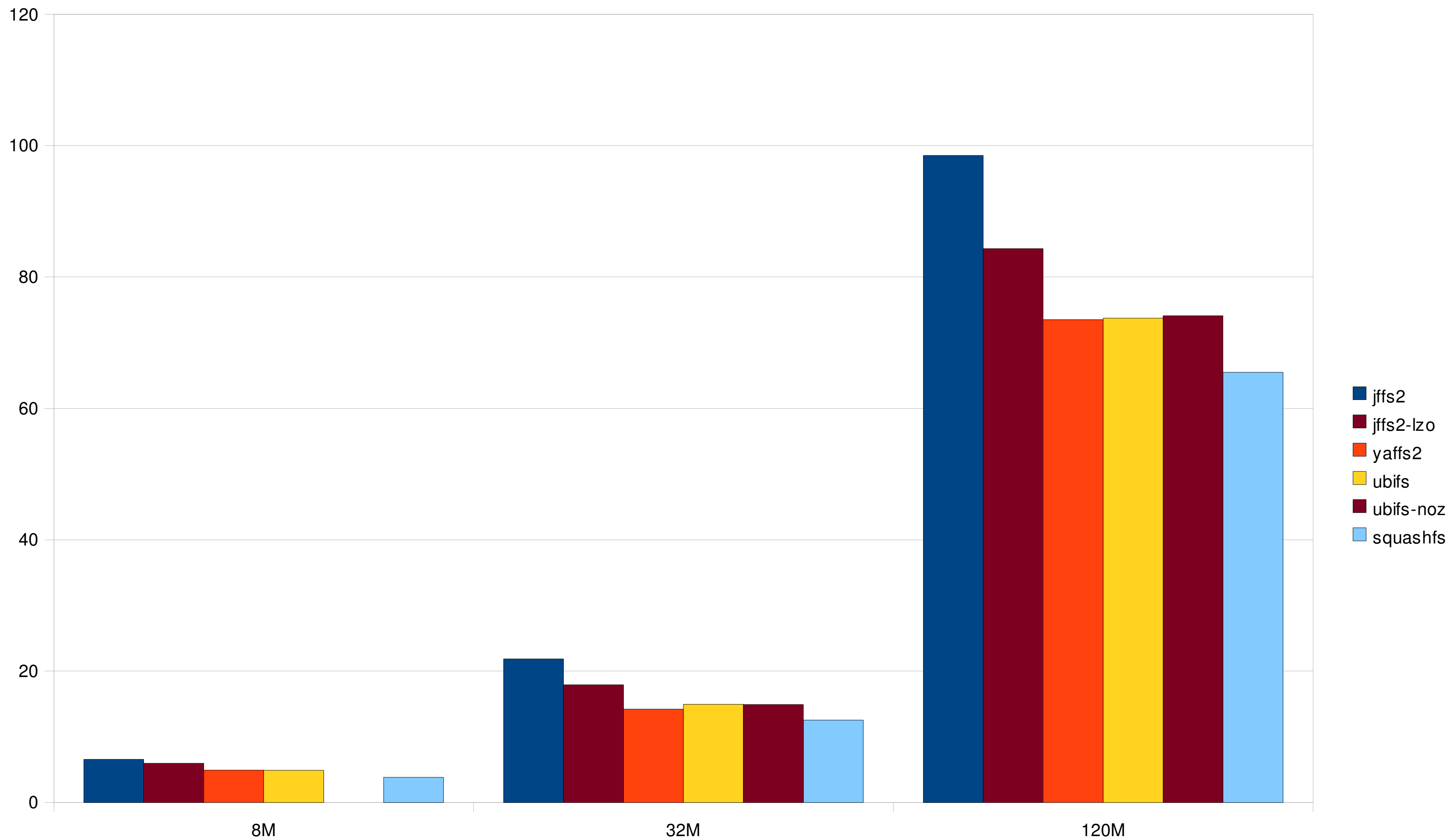


Zoom - Read time (seconds) - 8M



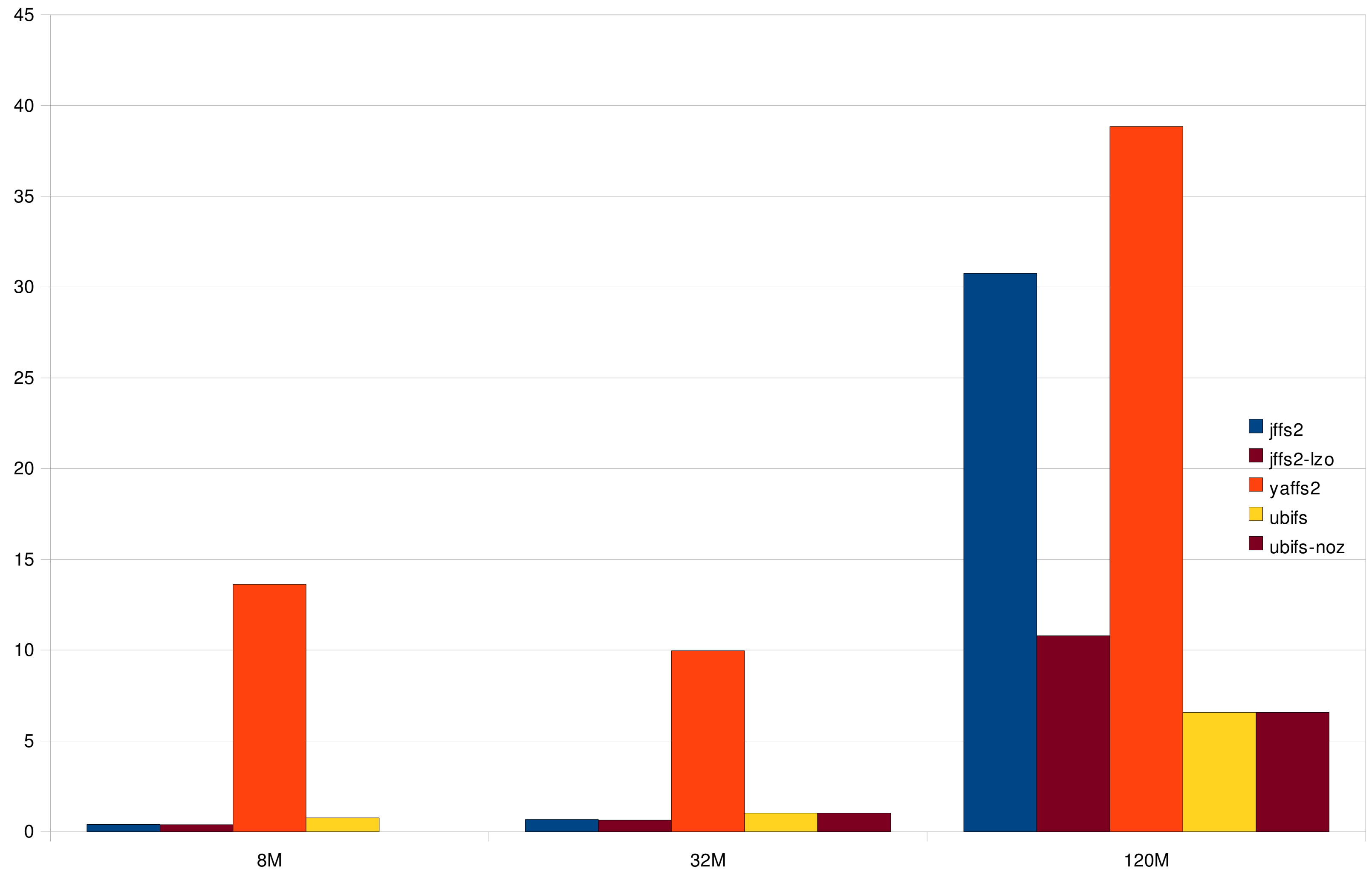
CPU usage during read (seconds)

During the experiments in the previous slide
(using the sys measure from the time command)



File removal time (seconds)

Removing all the files in the partition
(after the read experiment)

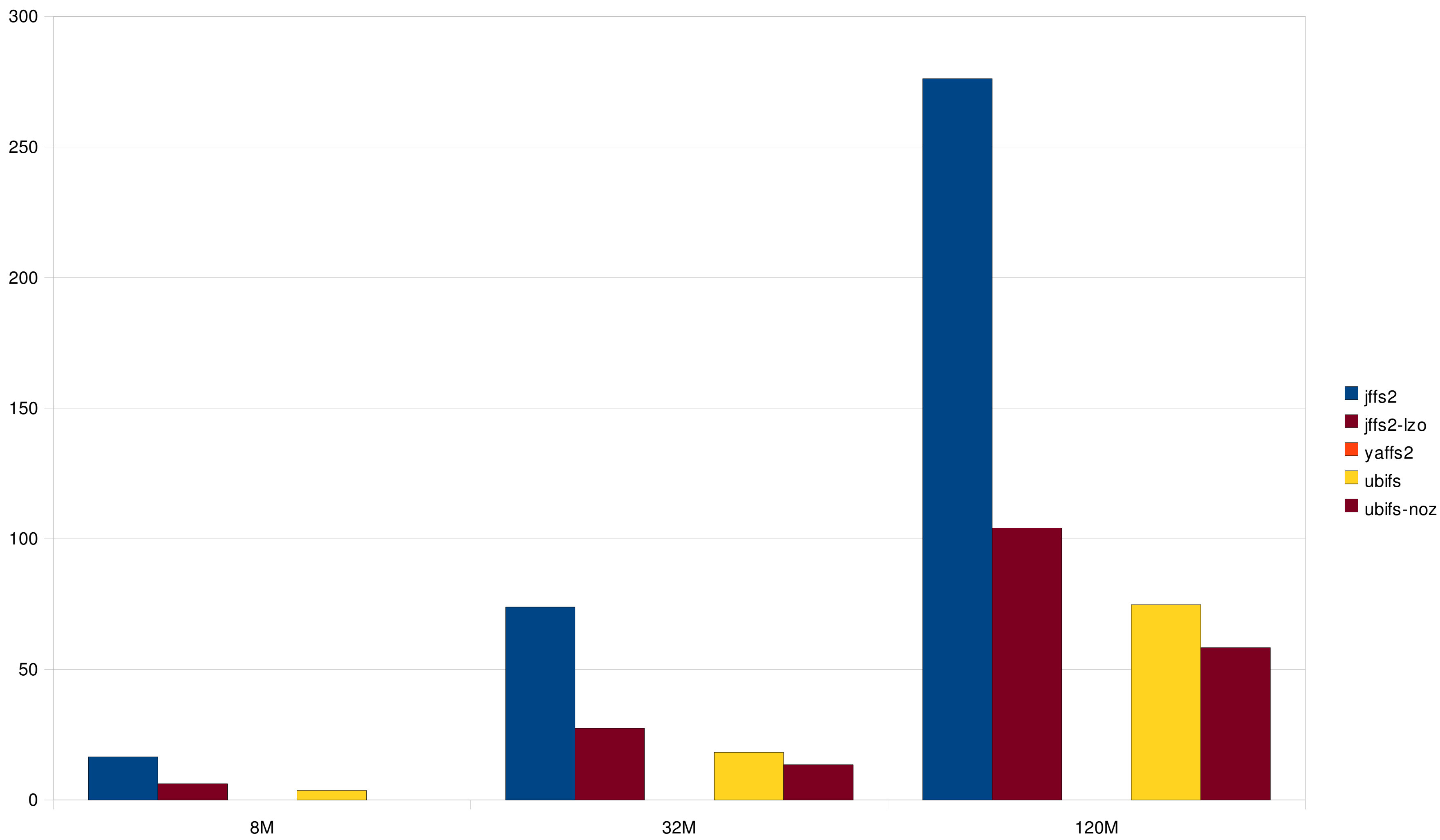


Write experiment

- Writing 8M directory contents multiple times
(less in the 8M case)
Data copied from a tmpfs filesystem,
for no overhead reading the files.
- Contents: arm Linux root filesystem.
Small to medium size files, mainly executables and shared libraries.
- Not many files that can't be compressed.

Write time (seconds)

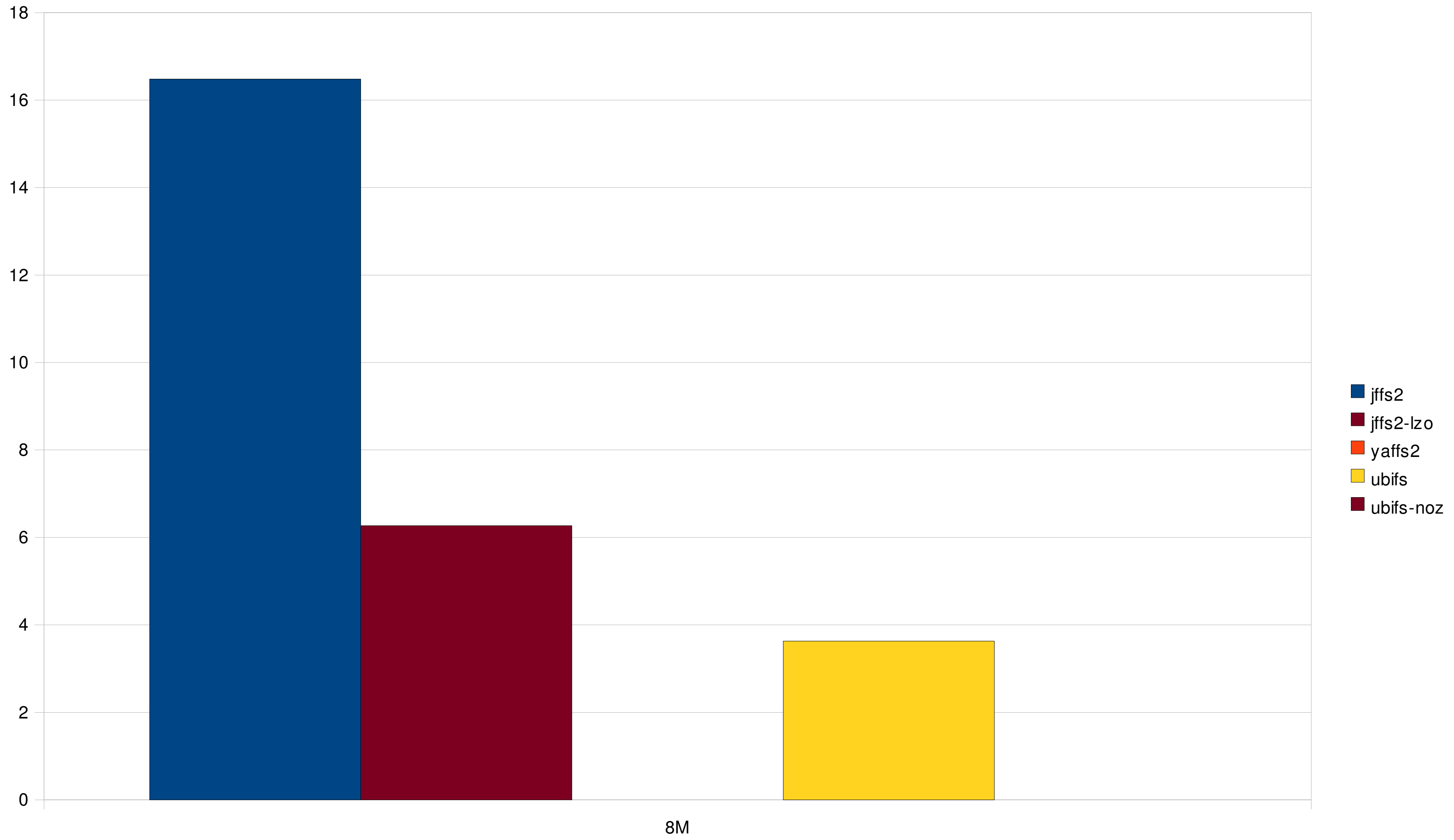
yaffs2 / 8M-32M-120M: doesn't fit
ubifs-noz / 8M: doesn't fit



Zoom - Write time (seconds) - 8M

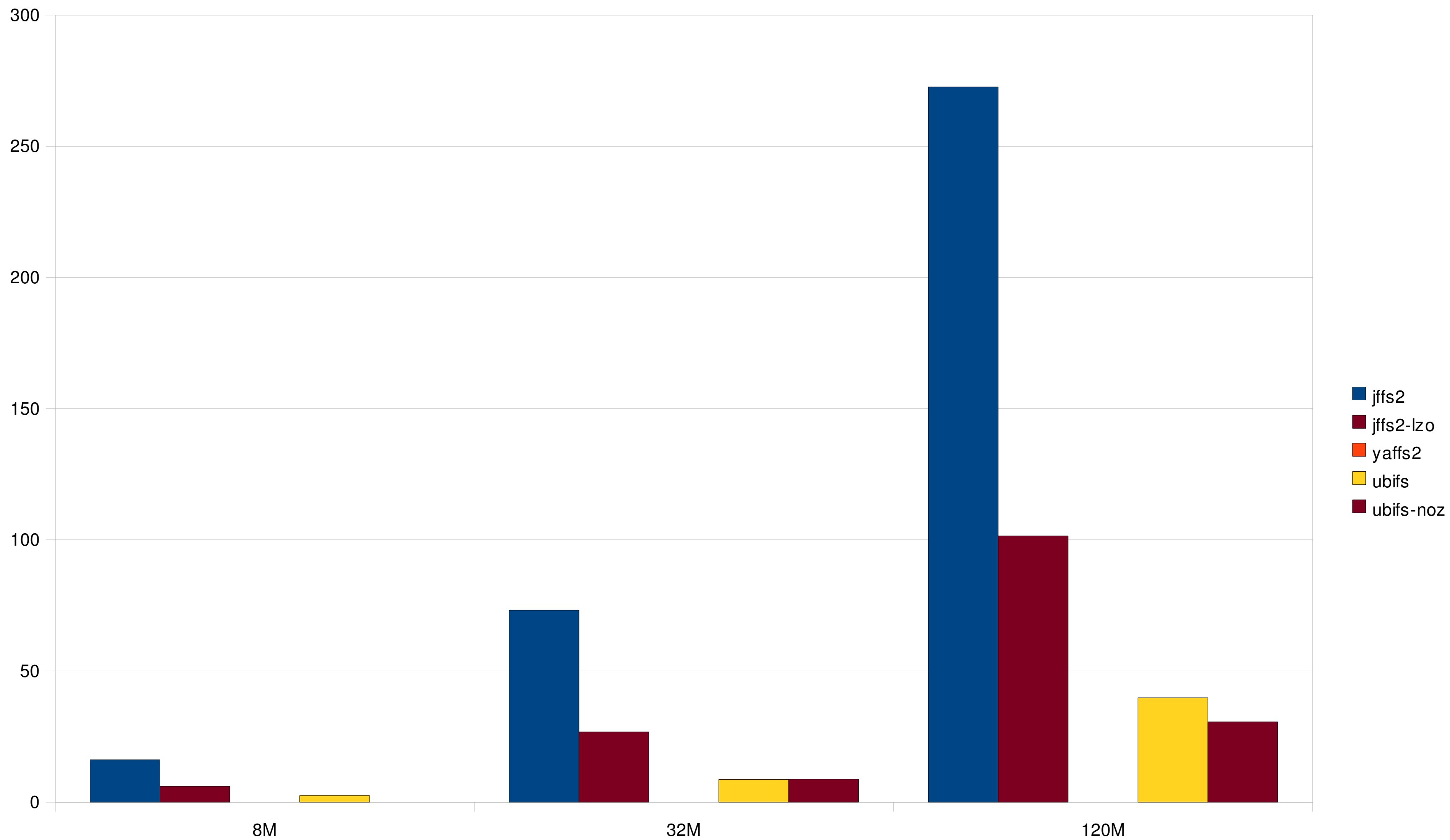
yaffs2 / 8M: doesn't fit

ubifs-noz / 8M: doesn't fit



CPU usage during write (seconds)

During the experiments in the previous slide
(using the sys measure from the time command)

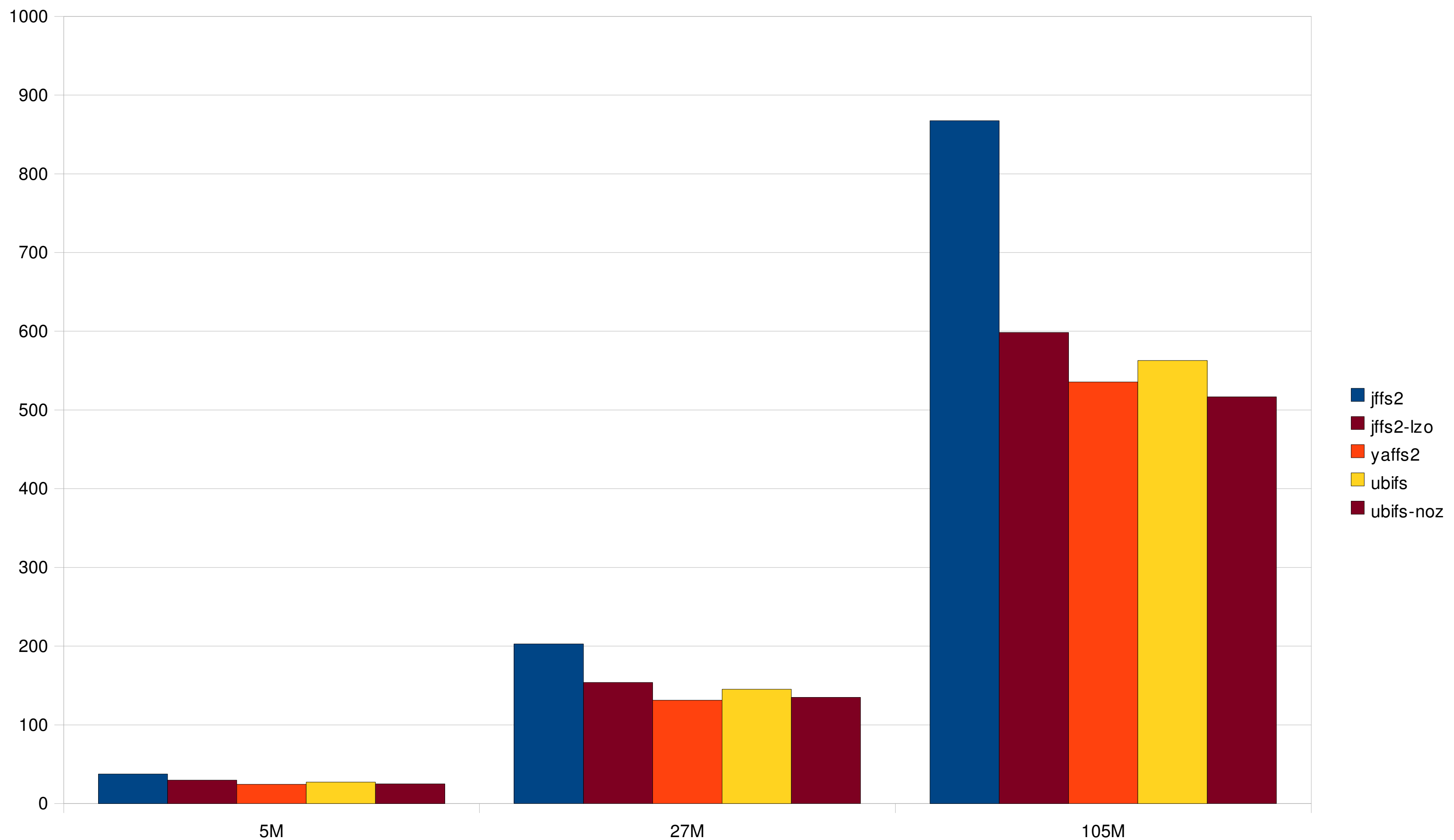


Random write experiment

- Writing 1 MB chunks of random data (copied from `/dev/urandom`).
- Trying to mimic the behavior of digital cameras and camcorders, recording already compressed data.

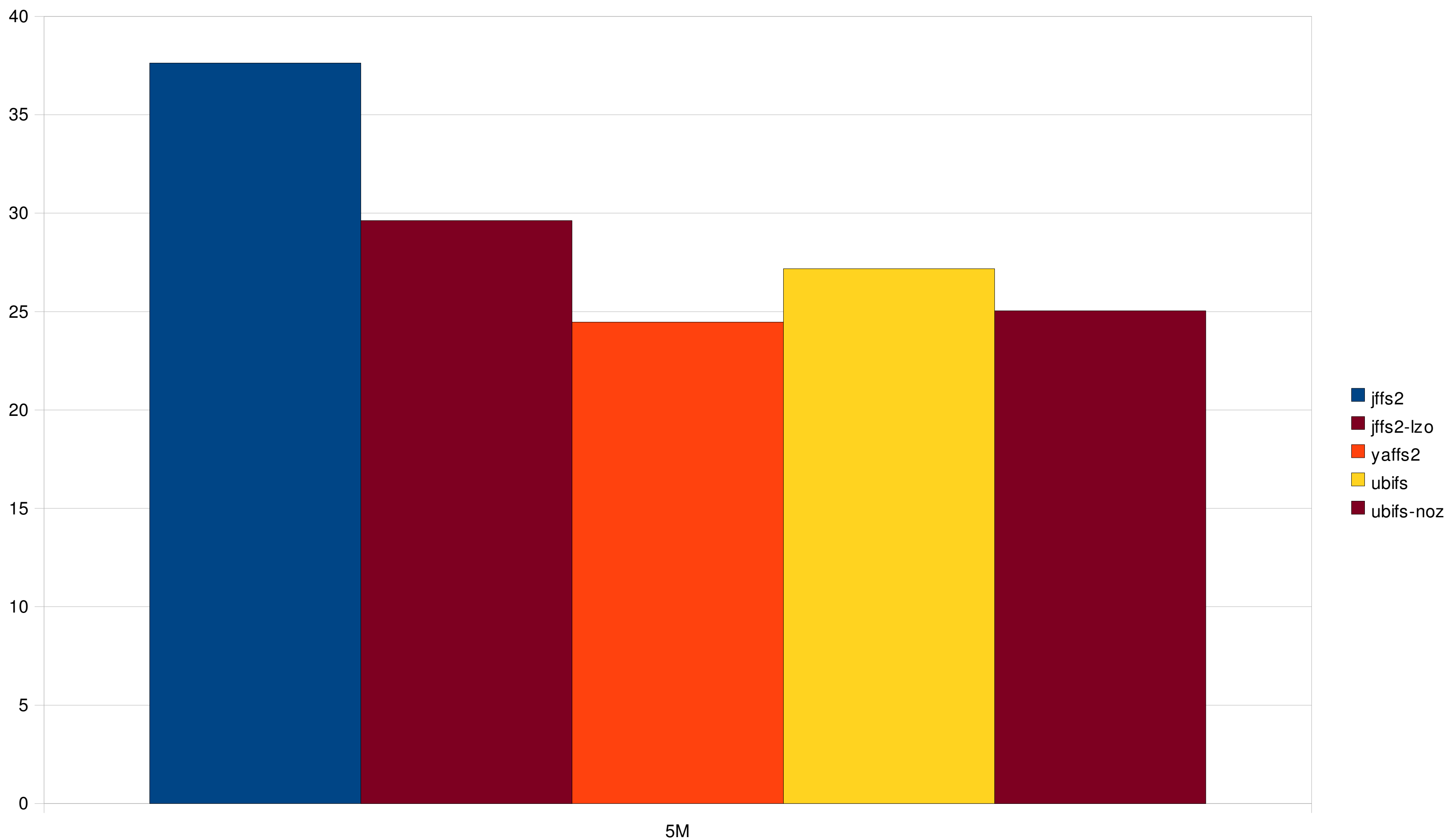
Random write time (seconds)

Caution: includes CPU time generating random numbers!



Zoom - Random write time (seconds) - 8M

Caution: includes CPU time generating random numbers!



Other experiments

UBIFS with only lzo support

- UBIFS supports both lzo (faster to compress and uncompress) and zlib (slower, but compresses better), and tries to find the best speed / size compromise.
- We tried UBIFS with only lzo support, hoping that having only one compressor would reduce runtime.
- Results: tiny differences in all benchmarks, even in CPU usage. (roughly between 0.1 and 1%).
- Conclusion: don't try to be too smart.
  The filesystem is already fine tuned
  to work great in most cases.

Suitability for very small partitions

8M MTD partition

- jffs2 fits 13 MB of files
  But probably doesn't leave enough free blocks
- UBI consumes 0.9 MB
  ubifs fits 6.6 MB of files

4M MTD partition

- jffs2 fits 5.1 MB of files
- UBI consumes 0.8 MB
  ubifs fits only 1.6 MB of files!

Bigger sizes: UBI overhead can be neglected:
32 MB: consumes 1.2 MB
128 MB: consumes 3.6 MB

What we observed

jffs2

- Dramatically outperformed by ubifs in most aspects.
- Huge mount / boot time.

yaffs2

- Also outperformed by ubifs.
- May not fit all your data
- Ugly file removal time (poor directory update performance?)
- Memory usage not scaling
- ubifs leaves no reason to stick to yaffs2.

ubifs

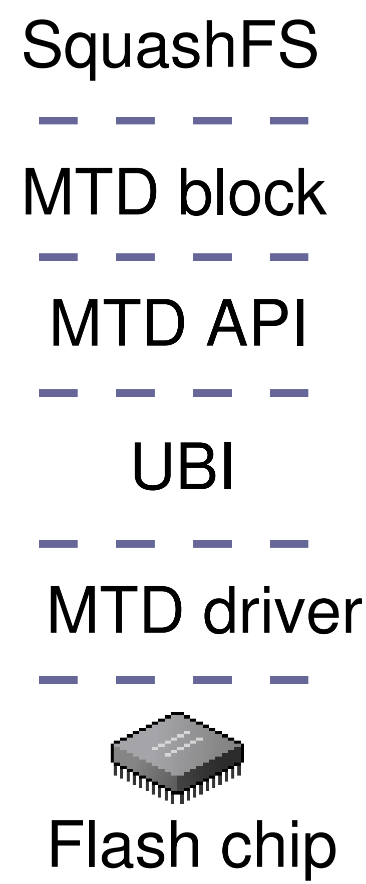
- Great performance in all corner cases.

SquashFS

- Best or near best performance in all read-only scenarios.

Conclusions

- Convert your jffs2 partitions to ubifs!
- It may only make sense to keep jffs2 for MTD partitions smaller than 10 MB, in case size is critical.
- No reason left to use yaffs2 instead of jffs2?
- You may also use SquashFS to squeeze more stuff on your flash storage. Advisable to use it on top of UBI, to let all flash sectors participate to wear leveling.



Current work

- Automate all these tests,
  to easily run then again with each new kernel version,
  and even with each -rc version!
- This will allow to quickly spot regressions
- Benchmarks results will be published on elinux.org
- Generic scripts will be released.
  We will officially support CALAO and BeagleBoard.

Thanks to CELF for sponsoring this work

Experimental filesystems (1)

A look at possible future solutions?

wikifs

- A CELF sponsored project.
- A Wiki structured filesystem (today's flash filesystems are log structured).
- Already used in Sony digital cameras and camcorders.
- Pros: direct / easy export of device functionality description to elinux.org.
- The author is in the room!

linuxtinyfs

- Targets small embedded systems.
- Negative memory consumption: achieved by compiling out the kernel file cache.
- Pros: very fast mount time
- Cons: a mount-only filesystem. Way to implement read and write not found yet.

Experimental filesystems (2)

fsckfs

- An innovative filesystem rebuilding itself at each reboot.
- Pros: no user space tools are needed.
  No `fsck.fsckfs` utility needed.
- Cons: mount time still needs improving.

Advice for flash-based block storage

Issues with flash-based block storage

- Flash storage made available only through a block interface.
- Hence, no way to access a low level flash interface and use the Linux filesystems doing wear leveling.
- No details about the layer (Flash Translation Layer) they use. Details are kept as trade secrets, and may hide poor implementations.
- Hence, it is highly recommended to limit the number of writes to these devices.

Reducing the number of writes

- Mount your filesystems as read-only, or use read-only filesystems (SquashFS), whenever possible.
- Keep volatile files in RAM (tmpfs)
- Use the `noatime` mount option, to avoid updating the filesystem every time you access a file. Or at least, if you need to know whether files were read after their last change, use the `relatime` option.
- Don't use the `sync` mount option (commits writes immediately). No optimizations possible.
- You may decide to do without journaled filesystems. They cause more writes, but are also much more power down resistant.

Useful reading

- Introduction to JFFS2 and LogFS:
  http://lwn.net/Articles/234441/
- Nice UBI presentation from Toshiba:
  http://free-electrons.com/redirect/celf-ubi.html
- Documentation on the linux-mtd website:
  http://www.linux-mtd.infradead.org/