SCHED_DEADLINE

Ongoing development and new features

ARM

Juri Lelli
ARM Ltd.

Linaro Connect BUD17, Budapest (Hungary)
08/03/2017

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

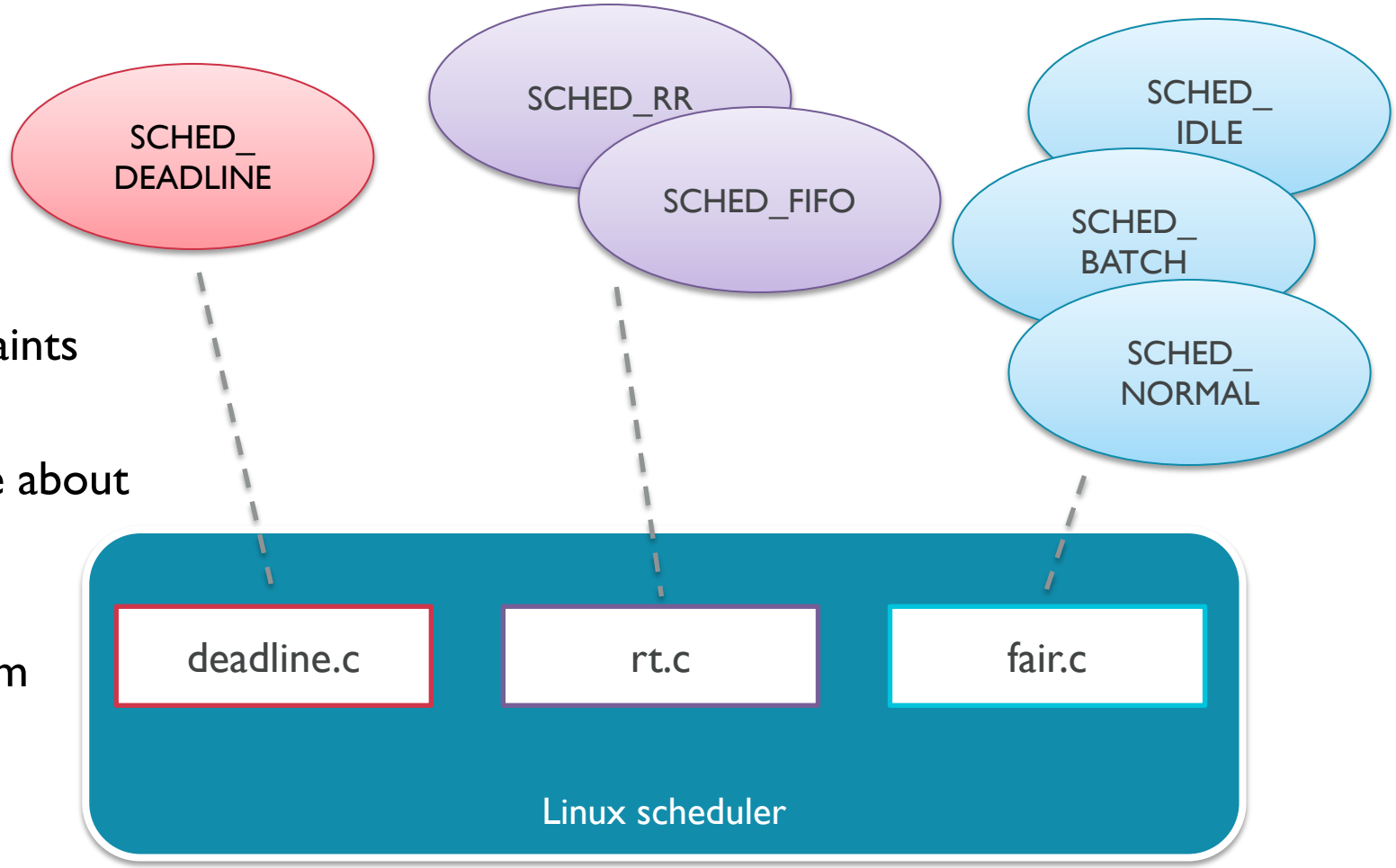
CHAPER 1
What and Why

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Deadline scheduling (previously on ...)

- mainline since v3.14
  30 March 2014 (~3y ago)
- it's not only about deadlines
  - RT scheduling policy
  - explicit per-task latency constraints
  - avoids starvation
  - enriches scheduler's knowledge about QoS requirements
  - EDF + CBS
  - resource reservation mechanism
  - temporal isolation
  - ELC16 presentation
    https://goo.gl/OVspuI



ARM

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Why is development now happening

- Energy Aware Scheduling (EAS)
  - extends the Linux kernel scheduler and power management to make it fully power/performance aware (https://goo.gl/vQbUOu)
  - scheduler modifications pertain to SCHED_NORMAL (so far)
- Android Common Kernel
  - EAS has been merged last year (https://goo.gl/FXCdAX)
  - performance usually means meeting latency requirements
  - considerable usage (and modifications) of SCHED_FIFO
  - SCHED_DEADLINE seems to be a better fit
    and mainline adoption of required changes *should be* less controversial

- Joint collaboration between ARM and Scuola Superiore Sant'Anna of Pisa

CHAPTER 2
Let's reclaim!

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Bandwidth Reclaiming

- PROBLEM
  - tasks' bandwidth is fixed (can only be changed with `sched_setattr()`)
  - what if tasks occasionally need more bandwidth?
    e.g., occasional workload fluctuations (network traffic, rendering of particularly heavy frame, etc)

- SOLUTION (proposed*)
  - bandwidth reclaiming: allow tasks to consume more than allocated
    - up to a certain maximum fraction of CPU time
    - if this doesn't break others' guarantees

* https://lkml.org/lkml/2016/12/30/107

Bandwidth Reclaiming (cont.)

- Greedy Reclamation of Unused Bandwidth (GRUB)[1]
- 3 components[2]
  - tracking of active utilization
  - modification of the accounting rule
  - multiprocessor support (original algorithm was designed for UP)

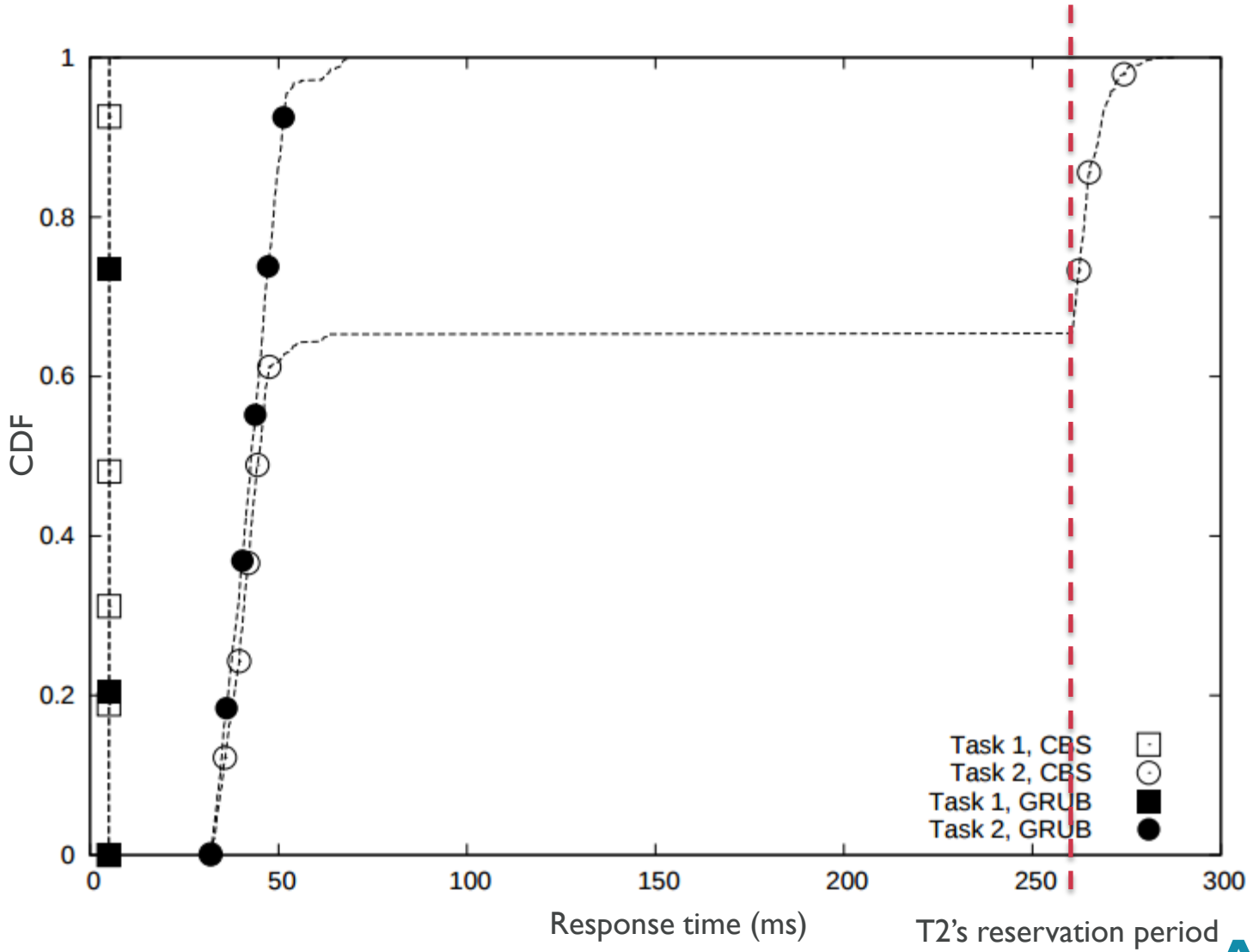
- for more details you are very welcome to attend the hacking session!

1 - Greedy reclamation of unused bandwidth in constant-bandwidth servers - Giuseppe Lipari, Sanjoy K. Baruah (https://goo.gl/xl4CUk)

2 - Greedy CPU reclaiming for SCHED DEADLINE - Luca Abeni, Juri Lelli, Claudio Scordino, Luigi Palopoli (https://goo.gl/e8EC8q)

Bandwidth Reclaiming (results)

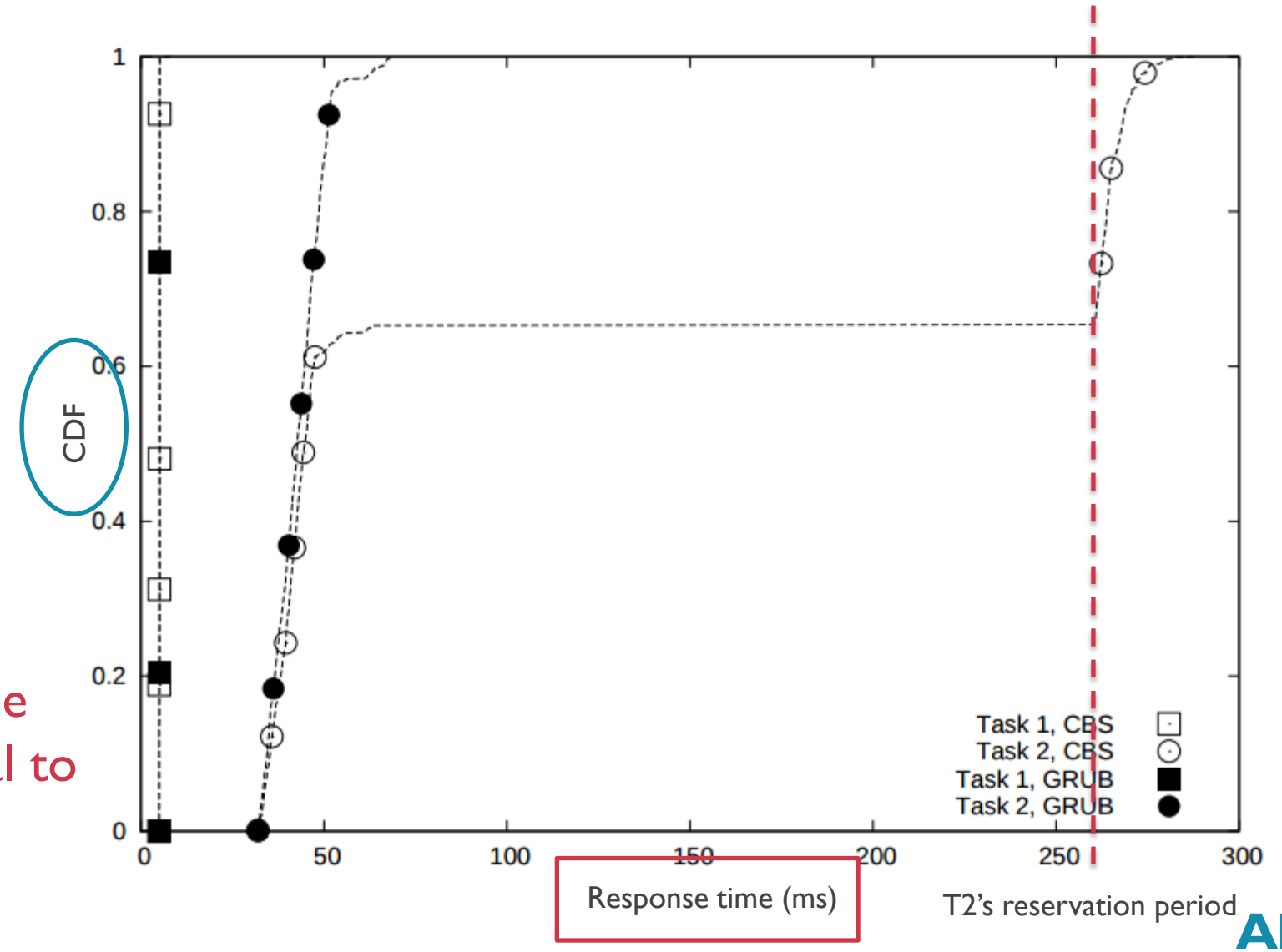
- Task1 (6ms, 20ms) constant execution time of 5ms
- Task2 (45ms, 260ms) experiences occasional variances (35ms-52ms)



Bandwidth Reclaiming (results)

- Task1 (6ms, 20ms) constant execution time of 5ms
- Task2 (45ms, 260ms) experiences occasional variances (35ms-52ms)

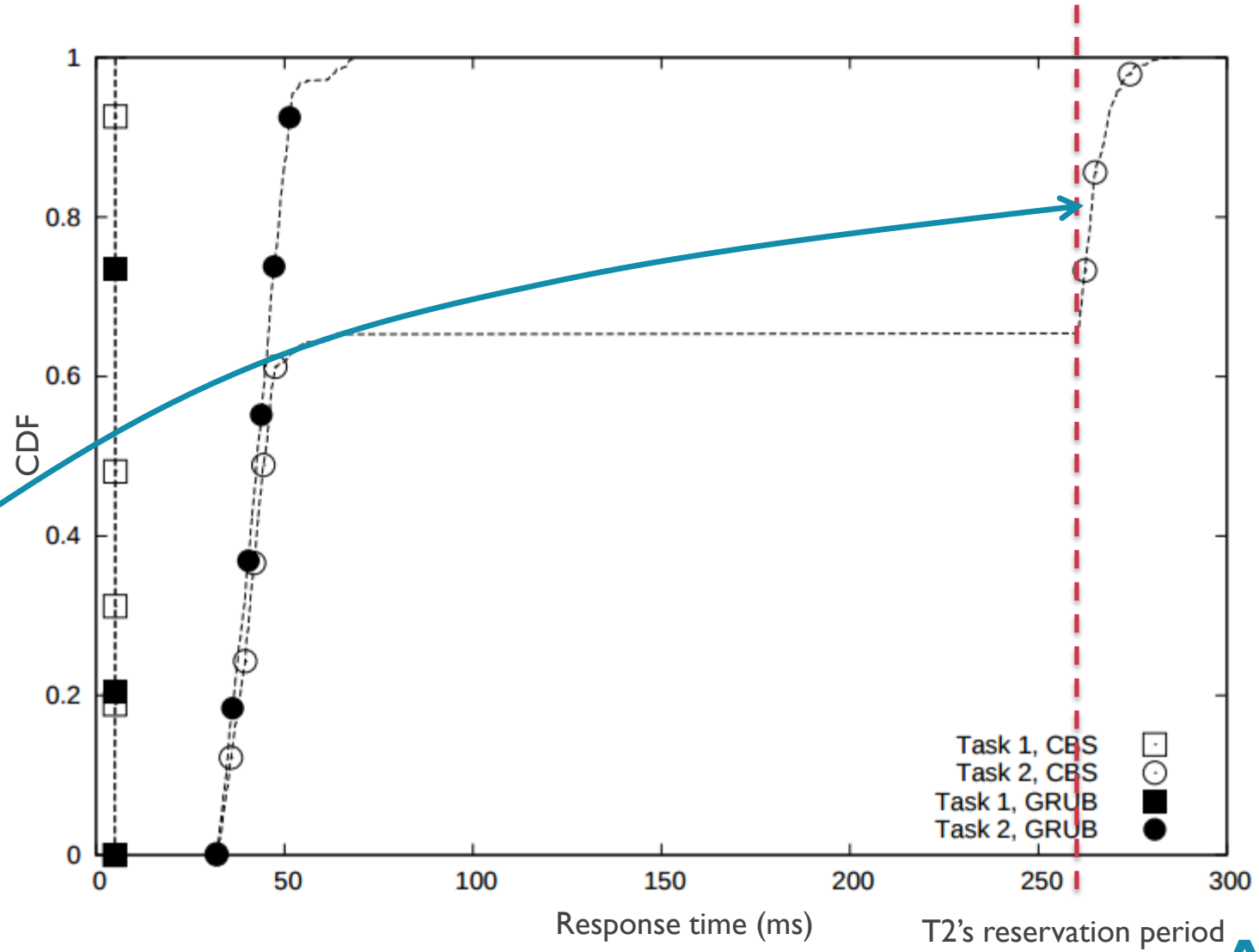
- Cumulative Distribution Function (CDF) probability that Response time will be less or equal to x ms



Bandwidth Reclaiming (results)

- Task1 (6ms, 20ms) constant execution time of 5ms
- Task2 (45ms, 260ms) experiences occasional variances (35ms-52ms)

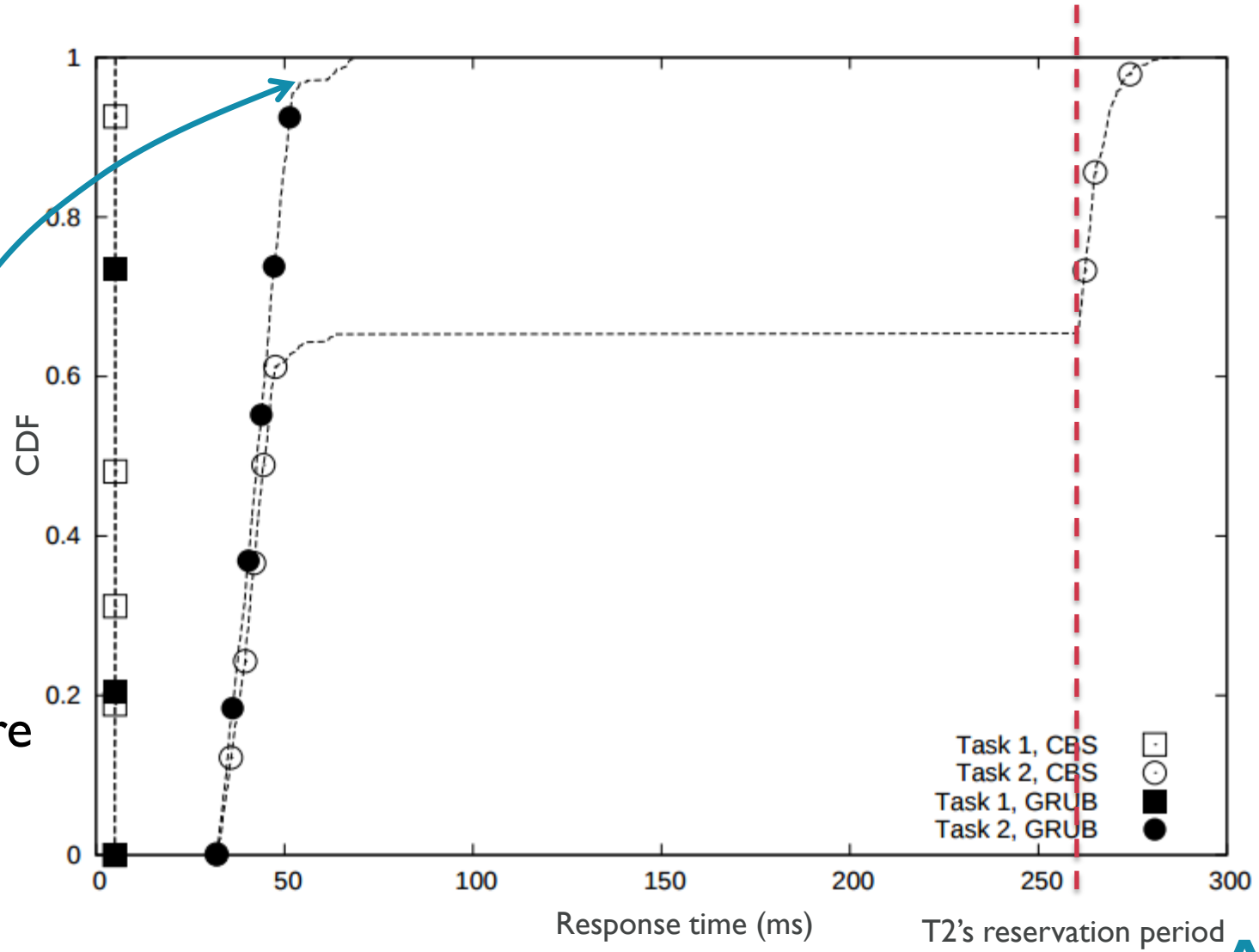
- Plain CBS
  T2's response time bigger then reservation period (~25%)



Bandwidth Reclaiming (results)

- Task1 (6ms, 20ms) constant execution time of 5ms
- Task2 (45ms, 260ms) experiences occasional variances (35ms-52ms)

- GRUB
  T2 always completes before reservation period (using bandwidth left by T1)



ARM

CHAPTER 3
Rock around the Clock (... and CPU)

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Frequency/CPU scaling

- Reservation runtime needs scaling according to frequency and CPU max capacity
- for frequency, use the ratio between max and current capacity to enlarge the runtime granted to a task at admission control

$$scaled\_runtime = original\_runtime \cdot \frac{max\_capacity}{curr\_capacity}$$

- similarly for CPU, but using the ratio between biggest and current CPU capacity
- nice example running on HiKey will be presented during the hacking session

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Driving frequency selection

- scaling clock frequency, while meeting tasks' requirements (deadlines)
- scheduler driven CPU clock frequency selection
  - schedutil cpufreq governor
    SCHED_NORMAL – uses `util_avg` (PELT)
    SCHED_FIFO/RR and SCHED_DEADLINE – go to max!
- once bandwidth reclaiming is in*
  - start using SCHED_DEADLINE's per-CPU utilization contribution (sum to others)
  - move CPU frequency selection triggering points (where DL utilization changes)
  - allow sugov kworker thread(s) to always preempt SCHED_DEADLINE tasks (and lower priority) – for `!fast_switch_enabled` drivers
- and again attend the hacking session for more details/results/fun

* Claudio Scordino (Evidence Srl) is helping with this.

CHAPTER 4
Groupies

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Group scheduling

- Currently, one to one association between tasks and reservations
- Sometime it might be better/easier to group a set of tasks into the same reservation
  - virtual machine threads
  - rendering pipeline
  - legacy application (that for example needs forking)
  - high priority driver kthread(s)
- Hierarchical/Group scheduling[1,2,3]
  - cgroups support
  - temporal isolation between groups (and single entities)

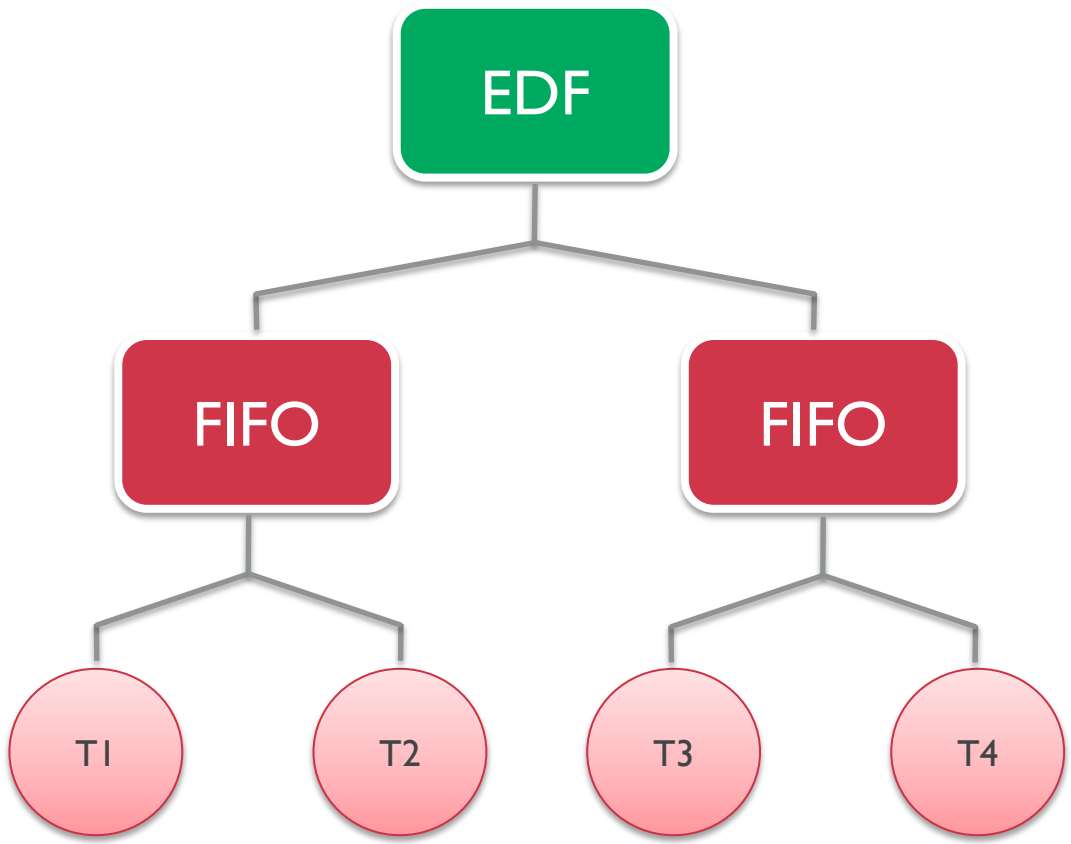
1 - A Framework for Hierarchical Scheduling on Multiprocessors - Giuseppe Lipari, Enrico Bini (https://goo.gl/veKrJy)

2 - Hierarchical Multiprocessor CPU Reservations for the Linux Kernel - F. Checconi, T. Cucinotta, D. Faggioli, G. Lipari (https://goo.gl/PIJaQe)

3 - The IRMOS real-time scheduler - T. Cucinotta, F. Checconi (https://lwn.net/Articles/398470/)

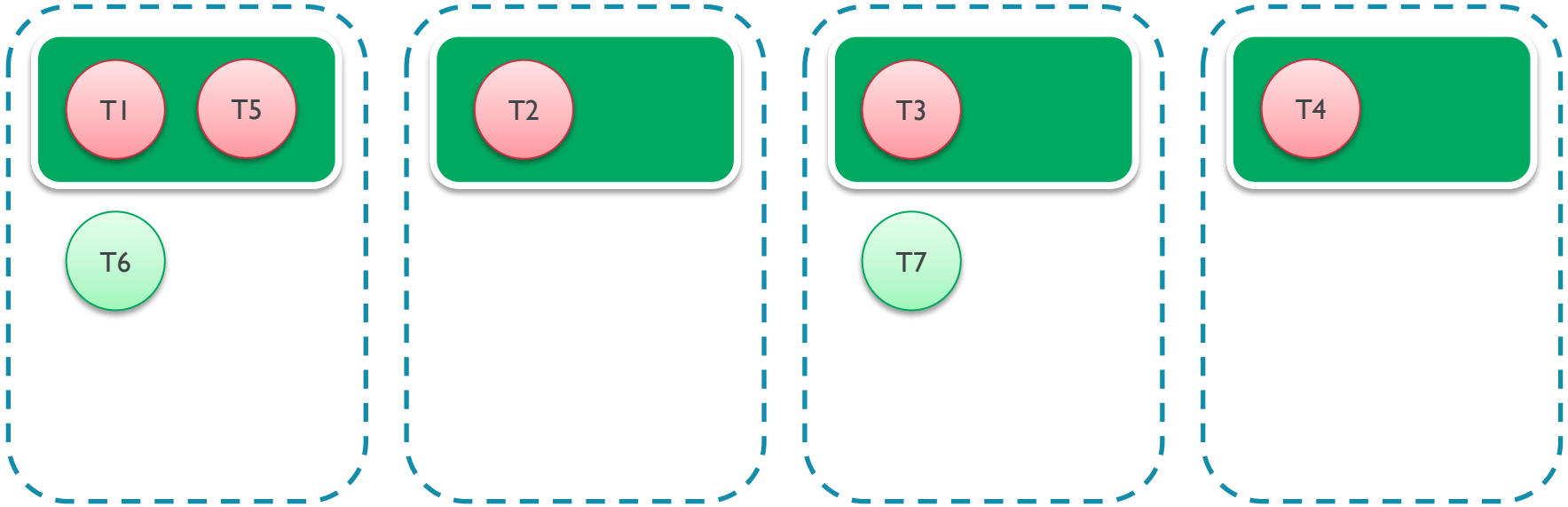
Group scheduling

- Hierarchical means
  - first level is EDF
  - second level is RT (FIFO/RR)
- Should eventually supplant RT-throttling



Group scheduling

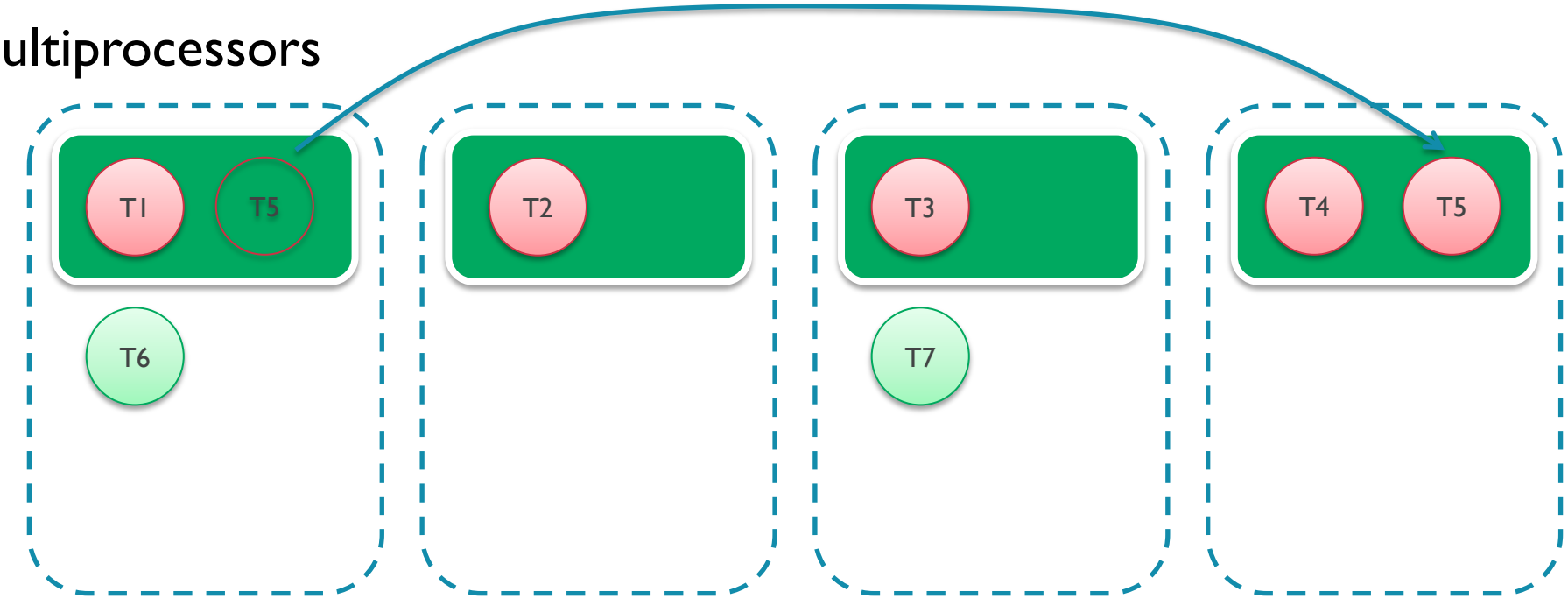
- On multiprocessors



- One DEADLINE group entity per CPU
- Coexists with single DEADLINE entities

Group scheduling

- On multiprocessors



- One DEADLINE group entity per CPU
- Coexists with single DEADLINE entities
- Sub RT entities get migrated according to G-FP (push/pull)

CHAPTER 5
It IS bright!

Agenda

- Deadline scheduling (SCHED_DEADLINE)
- Why is development now happening (out of the blue?)
- Bandwidth reclaiming
- Frequency/CPU scaling of reservation parameters
- Coupling with frequency selection
- Group scheduling
- Future

Future

- NEAR
  - experimenting with Android
  - reclaiming by demotion towards lower priority class
  - capacity awareness (for heterogeneous systems)
  - energy awareness (Energy Aware Scheduling for DEADLINE)

- NEAR(...ISH)
  - support single CPU affinity
  - enhanced priority inheritance (M-BWI most probably)
  - dynamic feedback mechanism (adapt reservation parameters to task' needs)

ARM

Get involved!

Shoot me an email <juri.lelli@arm.com>
Ask questions on LKML, linux-rt-users or eas-dev
Come join us @ OSPM-summit (https://goo.gl/ngTcgB)
... maybe remotely :-)

And don't forget to collect your prizes!!!