Peak Shaving: Applying limited-preemptive scheduling to peak load reduction in smart buildings

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Motivation

- Limit the peak load in a smart building
- Manage the activation of electric loads by a real-time scheduler
- Minimize the number of preemption

Picture: http://www.rcrwireless.com/wp-content/uploads/2016/07/32383041_l.jpg

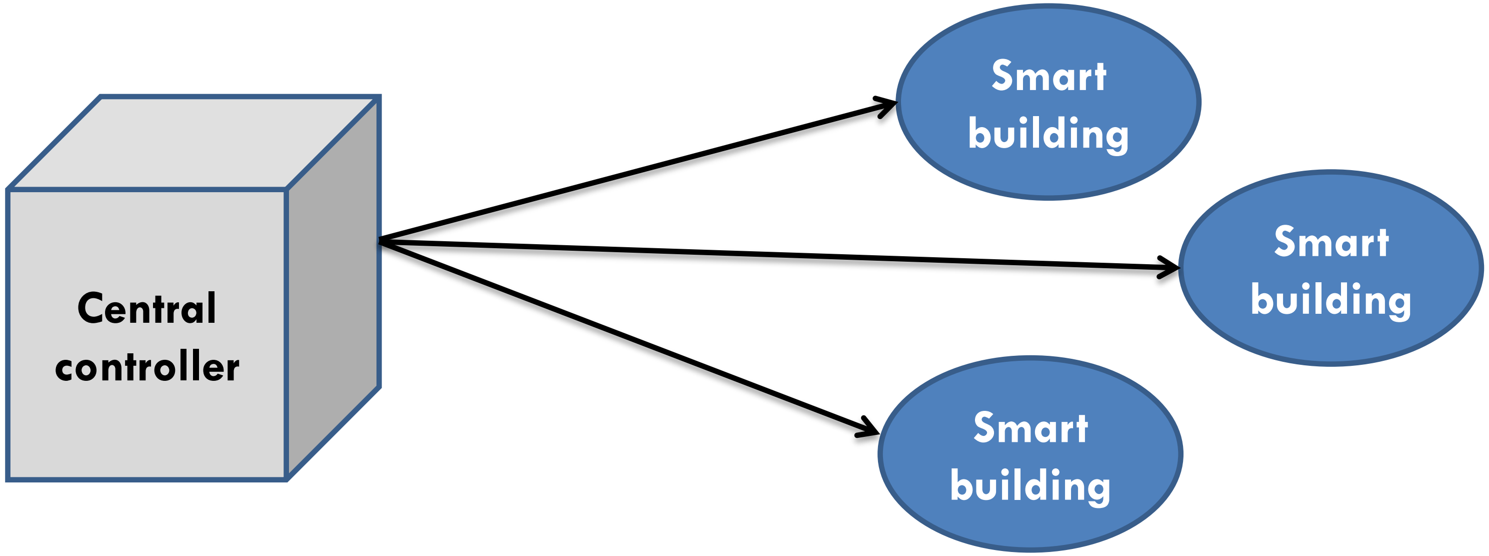
Outline

- Introduction
- Full-preemptive system
- Disadvantages of a Full-preemptive system
- Limited preemtive real-time scheduling
- Simulation result
- Conclusions

Introduction

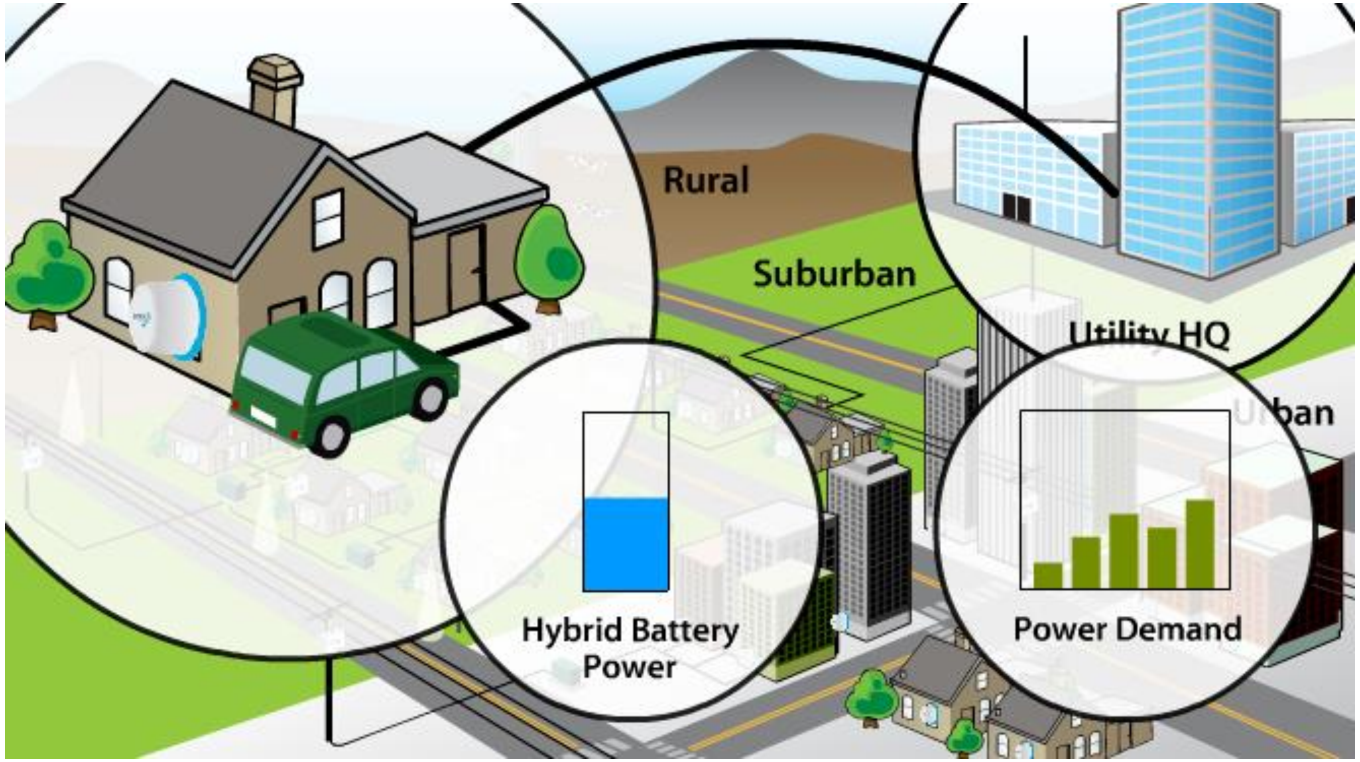
Demand-Side Management (DSM)

- A central controller is used in order to regulate the power demand in a set of smart building
  - Some appliance are stopped during certain time and restarted after
  - Thus decreases the power demand of entire building set
  - Avoids the deficiency of energy at supplier



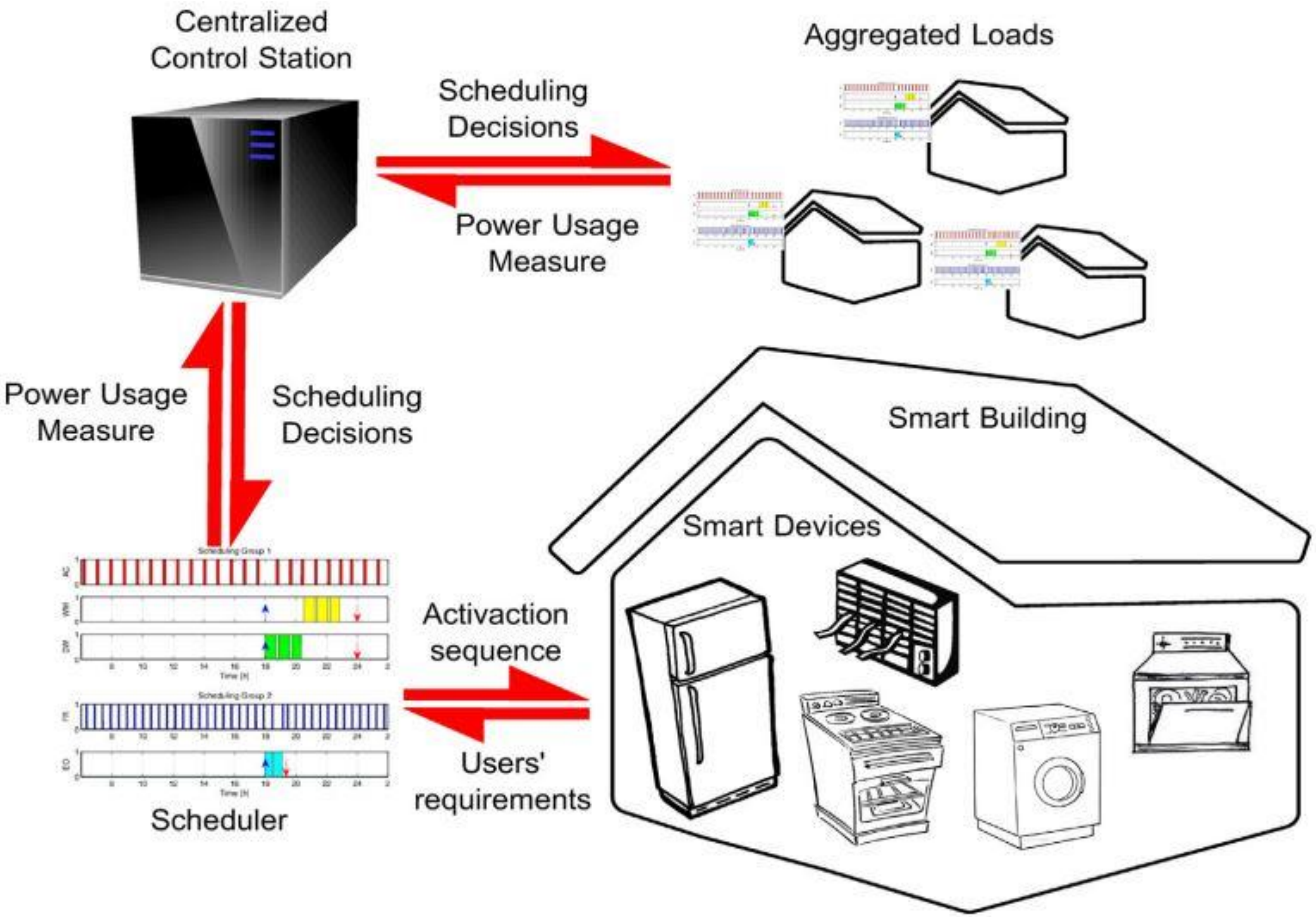
Demand-Side Management (DSM)

- A hybridbattery principe



Picture: http://climateinc.org/wp-content/uploads/2010/03/smart-grid.jpg

DSM with real-time scheduling



Picture: D. Caprino, M. Dova, and T. Facchinetti (2014) [3]

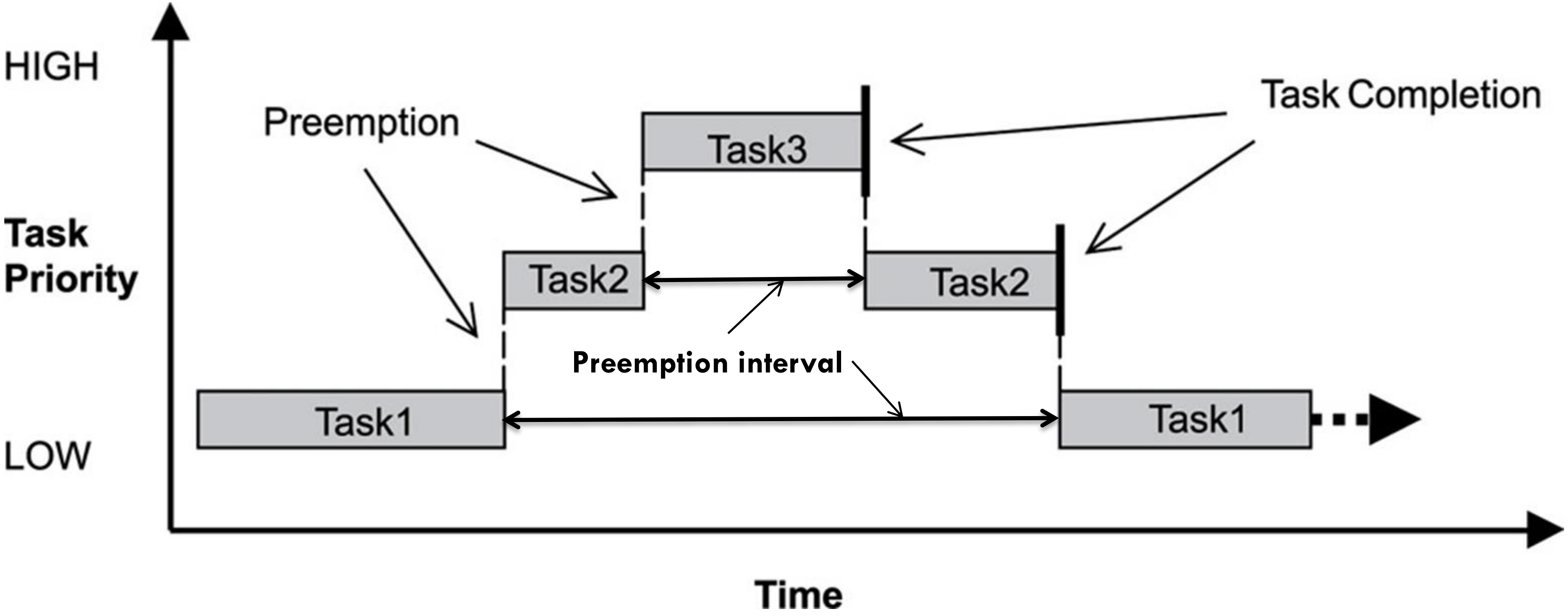
Fig. 1. The Home Energy Management system based on real-time control techniques.

Full-preemptive system

Definition

- **Full-preemptive system** is a model where every task can be interrupted at any time to allow the execution of a higher priority task
- **Preemption interval** is the time interval between the interruption of a tasks and its resumption

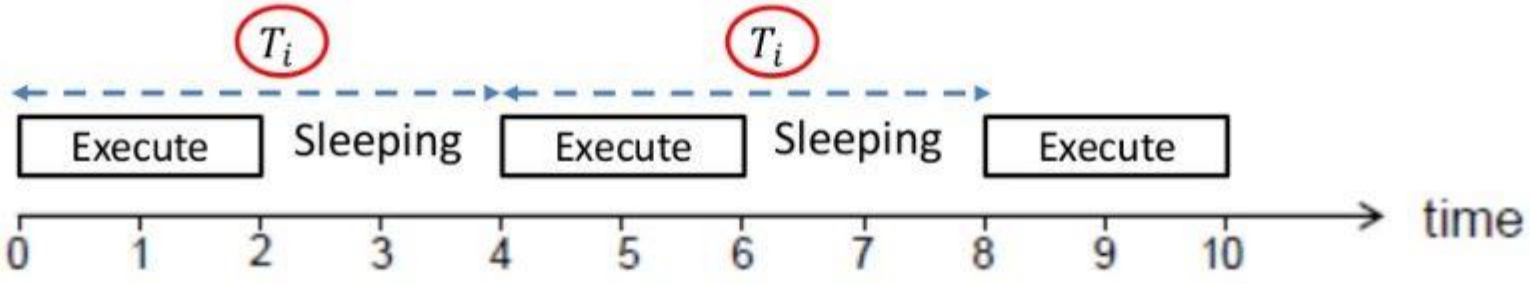
Illustration



Picture: http://www.embeddedlinux.org.cn/rtconforembsys/5107final/images/other-0405_0.jpg

Periodic activation

- **Periodic Task**: repeats in periodic intervals. E.g thermal loads.



Picture: http://de.slideshare.net/knowdiff/sara-afshar-scheduling-and-resource-sharing-in-multiprocessor-realtime-systems

T_i = minimum inter arrival time

Periodic activation

- A **thermal load** is a device whose task is to regulate the temperature of a given environment.

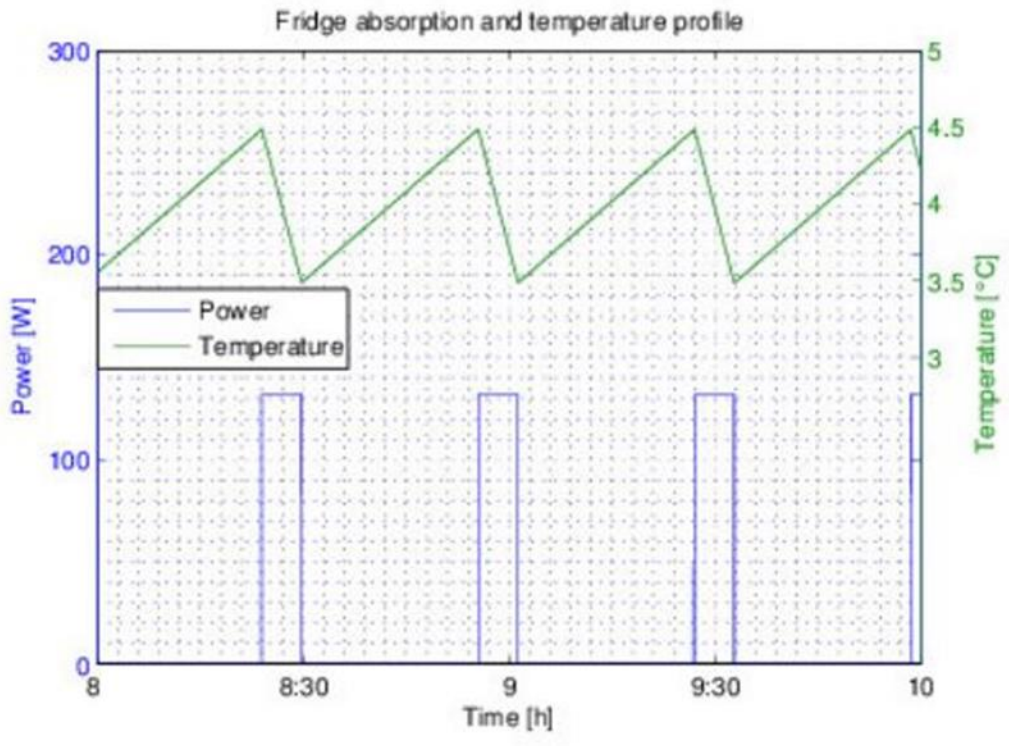
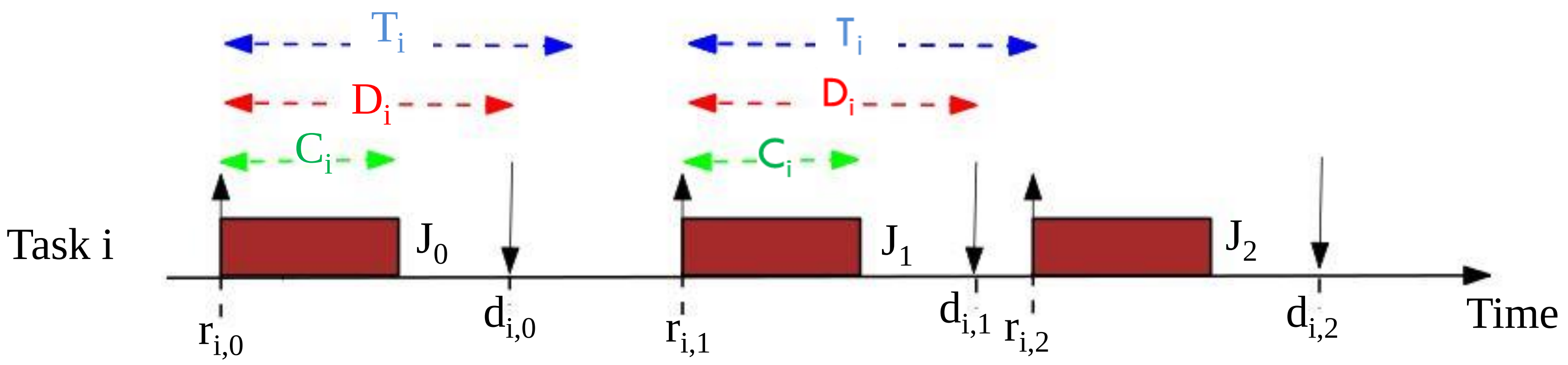


Fig. 1. Power and temperature profiles of a refrigerator. The set-point of the temperature is $4°\text{C} \pm 1$. The consumed power is 132 W.

Sporadic Tasks (as task model)

- The tasks are sporadic, when they
  - Can arrive at the system anytime, but with defined minimum inter-arrival times between two consecutive activations.
  - And are characterized by
    - Minimum inter-arrival time $\mathbf{T_i}$
    - Relative deadline $\mathbf{D_i \leq T_i}$
    - Activation time $\mathbf{C_i \leq D_i}$
    - Request time $\mathbf{r_{i,k}}$ whose $\mathbf{r_{i,k+1} \geq r_{i,k} + T_i}$

Sporadic Tasks (as task model)



- Absolute deadline $\mathbf{d_{i,j}}$ of a job. $\mathbf{d_{i,k} = r_{i,k} + D_i}$
- Job $\mathbf{J_i}$ is an activation of one task
- A sporadic task can generate infinitely many different legal sequences of Jobs

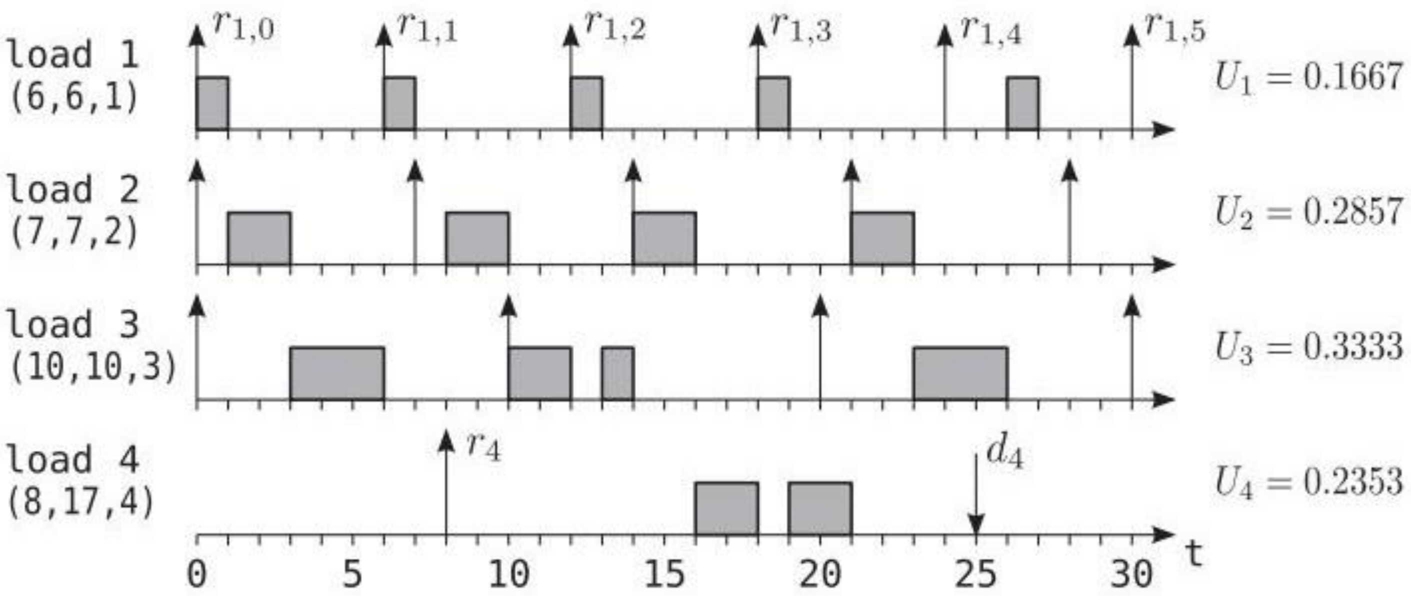
Advantages of using real-time scheduling techniques

- Efficiency
- Predictability
- Robustness
- Reusability
- Scalability
- Automation

Dynamic scheduling algorithm

- The **Earliest Deadline First** (EDF) algorithm dynamically assigns priorities according to deadline and is implemented only on a uniprocessor
  - Tasks having close deadline receive a high priority
  - Tasks having far deadline receive a low priority
- **Process**:
  - At anytime t, active the task whose deadline is closest to t
  - A task does not need to be periodic
  - But it needs to announce its deadline to the scheduler when it becomes activable

Dynamic scheduling algorithm



Picture: D. Caprino et al. (2014) [4]

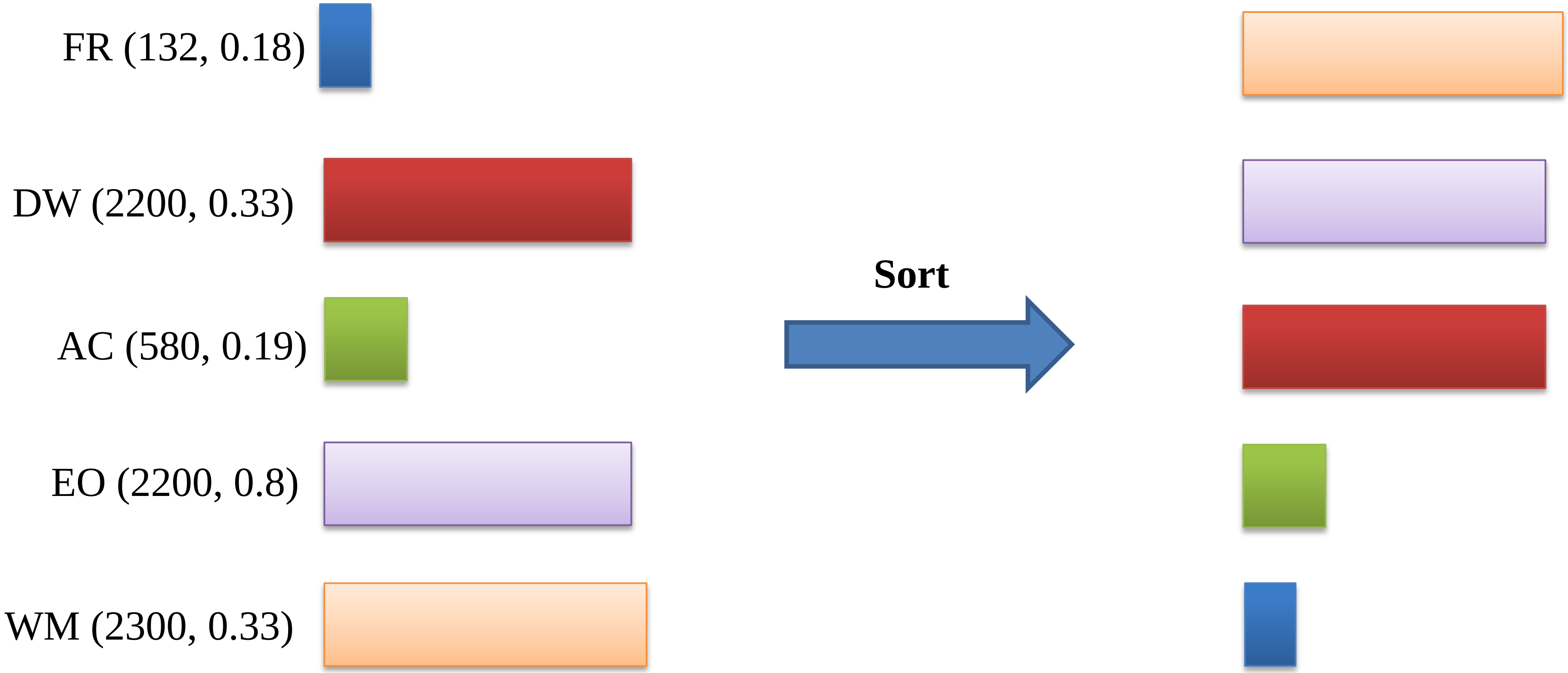
- EDF is **optimal** ⇔ the schedulability test is satisfied
  - System utilization $\mathbf{U = \sum_i U_i}$, $\mathbf{U \leq 1}$.
  - Task utilization $\mathbf{U_i = C_i/T_i}$
- When $\mathbf{U > 1}$ ⇒ simultaneous activaction of loads
  - The upper bound (on the peak load of power demand) is strong to determinate

Load partitioning algorithm

- Assigns load into groups ($\Omega_1,\ldots,\Omega_m$) called **scheduling groups**
- based on heuristic method
  - **First-Fit Decreasing Height (FFDH)**
- **FFDH**
  - Create least possible scheduling groups
  - Order the load in each scheduling groups according to decreasing power demand
  - Ensures satisfiability of the schedulability test in each scheduling group

Load partitioning algorithm

- FFDH **process**
  - Device ($\mathbf{P_i}$, $\mathbf{U_i}$), $\mathbf{P_i}$ is the nominal load power demand and represents the “**Height**“
  - **Phase 1: Sort**



FR (132, 0.18)

DW (2200, 0.33)

AC (580, 0.19)

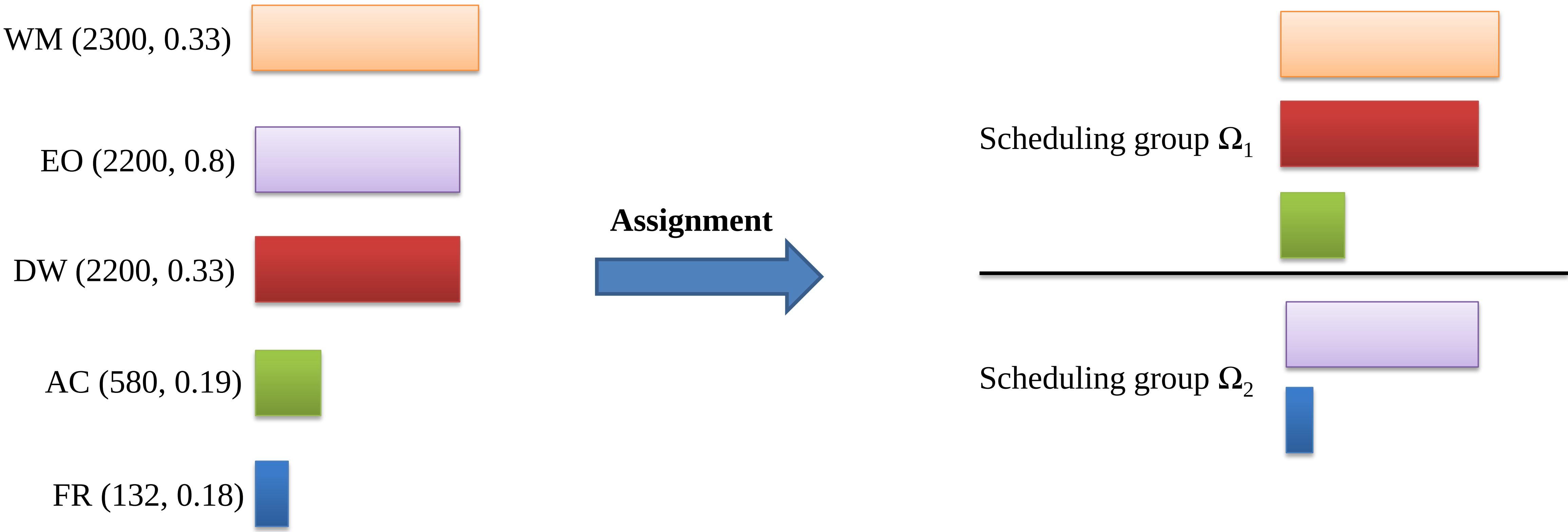
EO (2200, 0.8)

WM (2300, 0.33)

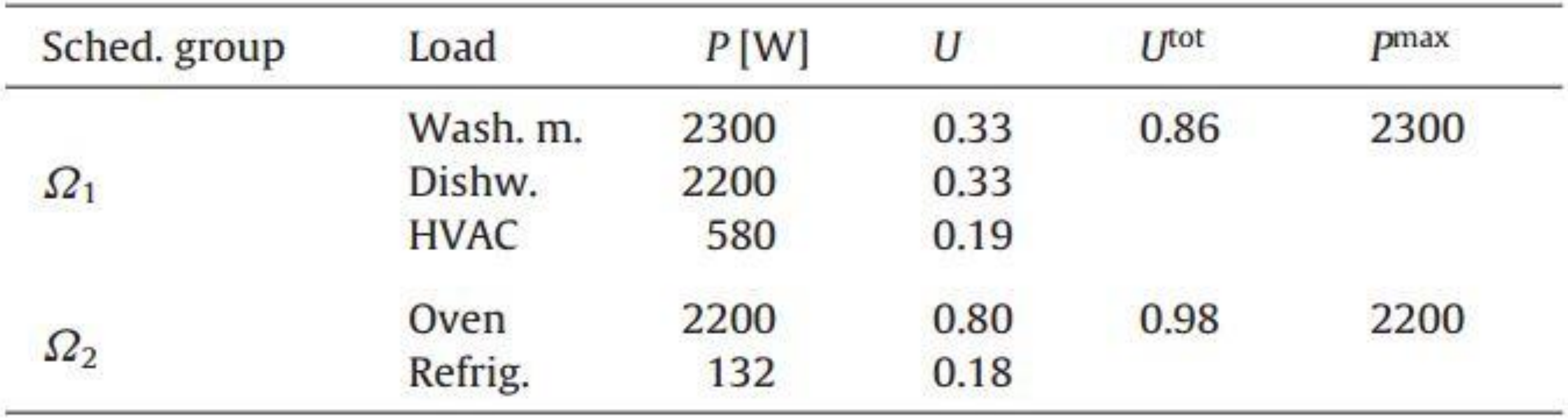
Sort

Load partitioning algorithm

- FFDH **process**
  - **Phase 2: Assignment**



Load partitioning algorithm



Sched. group	Load	P [W]	U	U^{tot}	P^{max}
Ω_1	Wash. m.	2300	0.33	0.86	2300
	Dishw.	2200	0.33		
	HVAC	580	0.19		
Ω_2	Oven	2200	0.80	0.98	2200
	Refrig.	132	0.18		

Picture: D. Caprino et al. (2014) [4]

In short

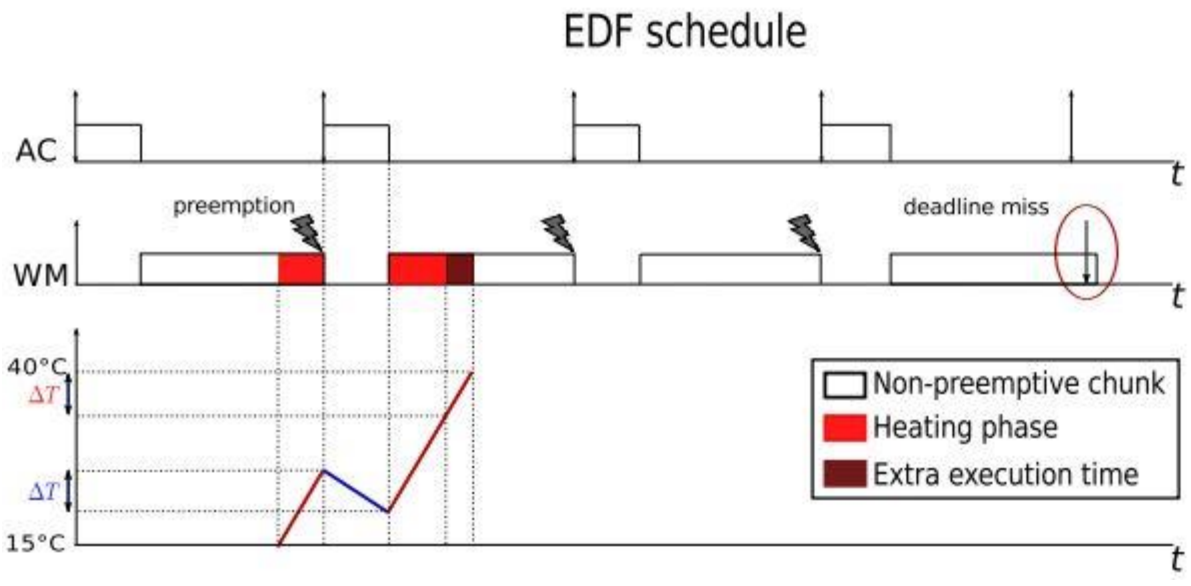
- EDF schedules tasks in each group independently from other groups
  - Only one load is active in each scheduling group at any given time
- Full preemptive system ensures that an upper bound of the peak load can be determinated
  - The maximum peak load is obtained when the loads having the highest power demand are simultaneously activated in all the scheduling groups
  - But can not guarantee the minimun peak load

Disadvantages of a Full-preemptive system

Effects of preemptions on load scheduling

- The tasks can miss their deadline due to Extra-time added to their execution time
  - Violation of timing constraints
- Impacts on lifetime of component (deterioration of appliances)

Effects of preemptions on thermal loads



- An **overhead** is an extra-time added to the “regular” activation time of the load

Effects of preemptions on thermal loads

- The extra-time is calculated as follows
  - $\boldsymbol{\alpha}^{\mathbf{on}}$ be the constant rate of an increasing temperature
  - $\boldsymbol{\alpha}^{\mathbf{off}}$ is constant rate of the decreasing temperature
  - The extra activation time $\Delta\mathbf{C}_{\mathbf{i,j}}$ of the j-th job of the i-th load is

$$\Delta C_{i,j} = \frac{\alpha_i^{\text{off}}}{\alpha_i^{\text{on}}}\, t_{i,j}^{\text{stop}}$$

  - $\mathbf{t}_{\mathbf{i,j}}^{\mathbf{stop}}$ is the sum of the durations of all preemption intervals occurring during the heating phase

LIMITED-PREEMPTIVE REAL-TIME SCHEDULING

Definition

- **Limited-preemptive scheduling** aims to decrease the number of preemptions occurring at run-time
- A **non-preemptive chunk** is a continuous time interval during which the running task is executed without being interrupted

Principle

- Calculate the non-preemptive chunks of each task
- Put the jobs of one task as far as possible within one of its non-preemptive chunks
- A higher priority can not interrupt the running task that is in one of its non-preemptive chunks, consequently
  - It is placed in an queue
  - And activate at the end of the non-preemptive chunk of the running task.

Calculation of non preemptive chunk

- Let $\mathbf{b_i}$ the duration of the largest non-preemptive chunk
- Calculate an upper bound $\mathbf{T^*}$ such that $d_k \leq \mathbf{T^*}$
- Calculate the **Demand Bound Function (DBF)**
- Calculate the value of the **SLACK($\mathbf{d_k}$) function** related to every deadline $d_1, \ldots, d_n$

Calculation of non preemptive chunk

- **Upper bound T***

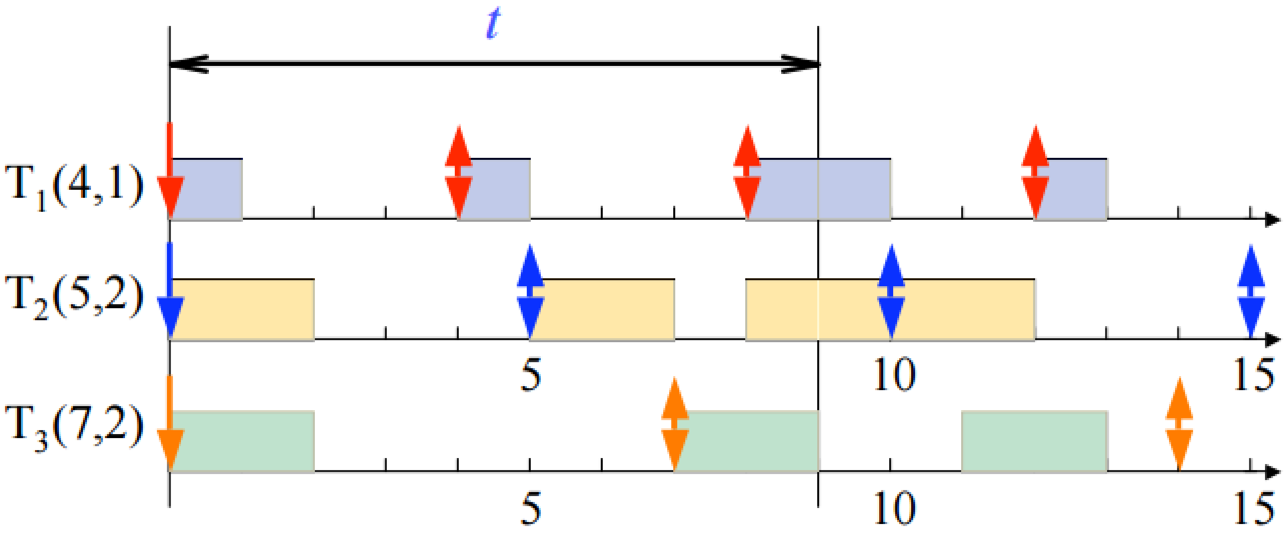
$$T^*(\tau) \overset{\text{def}}{=} \min\left[P, \max\left(d_{\max}, \frac{1}{1-U}\sum_{i=1}^{n} U_i \cdot (T_i - d_i)\right)\right]$$

- Some notation
  - Hyperperiod $P \overset{\text{def}}{=} \mathrm{lcm}(T_1, \ldots, T_n)$
  - Task system τ
  - System utilization U
  - Task Utilization U_i
  - Deadline d_i
  - Minimum inter arrival time T_i
  - Execution time C_i

Calculation of non preemptive chunk

- **Demand Bound Function (DBF)**
  - computes the large number of the execution time of all job that can be generate by the task τ_i whose request time und deadline are in a time interval of length **t**

$$\mathrm{DBF}(\tau_i, t) \overset{\mathrm{def}}{=} \max\left(0, \left(\left\lfloor \frac{t-d_i}{T_i} \right\rfloor + 1\right) \times C_i\right)$$



Task(min inter arrival time, execution time)

Picture: http://www.cis.upenn.edu/~lee/06cse480/lec-real-time-scheduling.pdf

Calculation of non preemptive chunk

- **SLACK(B_k) function**

$$\mathrm{SLACK}(B_1) = B_1 - \sum_{\tau_i \in \tau} \mathrm{DBF}(\tau_i, B_1)$$

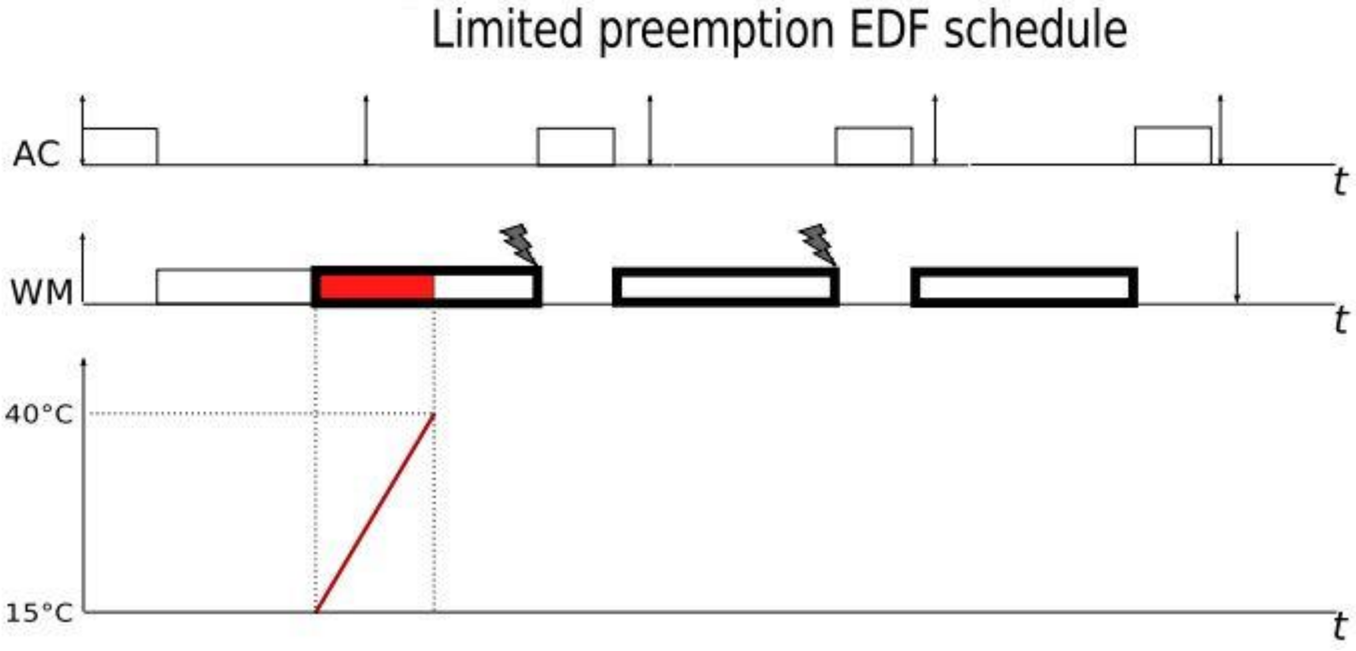
$$\mathrm{SLACK}(B_k) = \min\left(\mathrm{SLACK}(B_{k-1}), B_k - \sum_{\tau_i \in \tau} \mathrm{DBF}(\tau_i, B_k)\right)$$

- It is worth to notice that B_k represent a time-instant, $B_k \leq B_{k+1}$

Calculation of non preemptive chunk

- **Algorithm**
  - Input: task set τ ($\tau_1, \ldots, \tau_n$) and the time-instants B_1, B_2, …
  - Calculate SLACK(B_1)
  - For $k \leftarrow 2, 3, \ldots$ do
    - If $B_k > T^*(\tau)$ then return **feasible**
    - Calculate SLACK(B_k)
    - If SLACK(B_k) < 0 then return **infeasible**
    - If $B_k = d_j$ for some task τ_1, $1 \leq j \leq n$ then $b_j \leftarrow$ SLACK(B_k)

Example of application



SIMULATION RESULTS

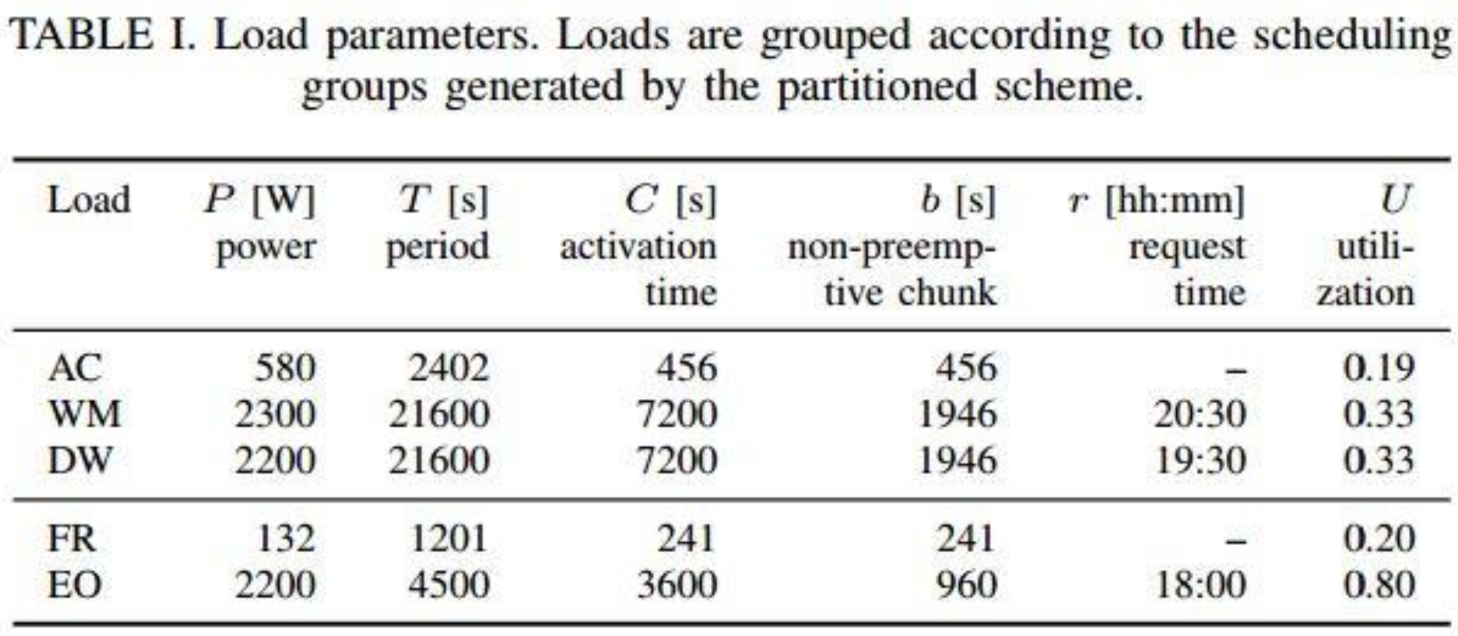
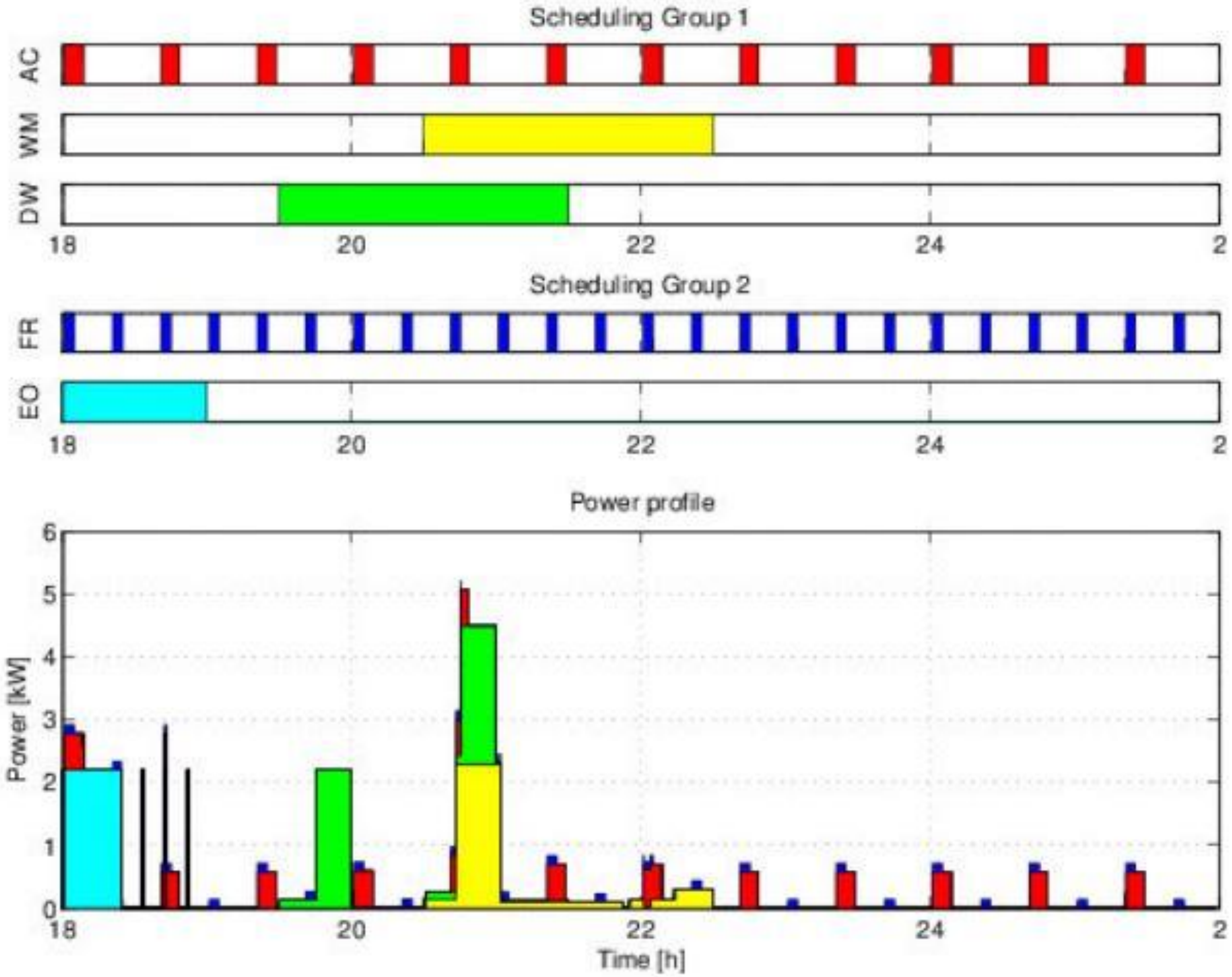
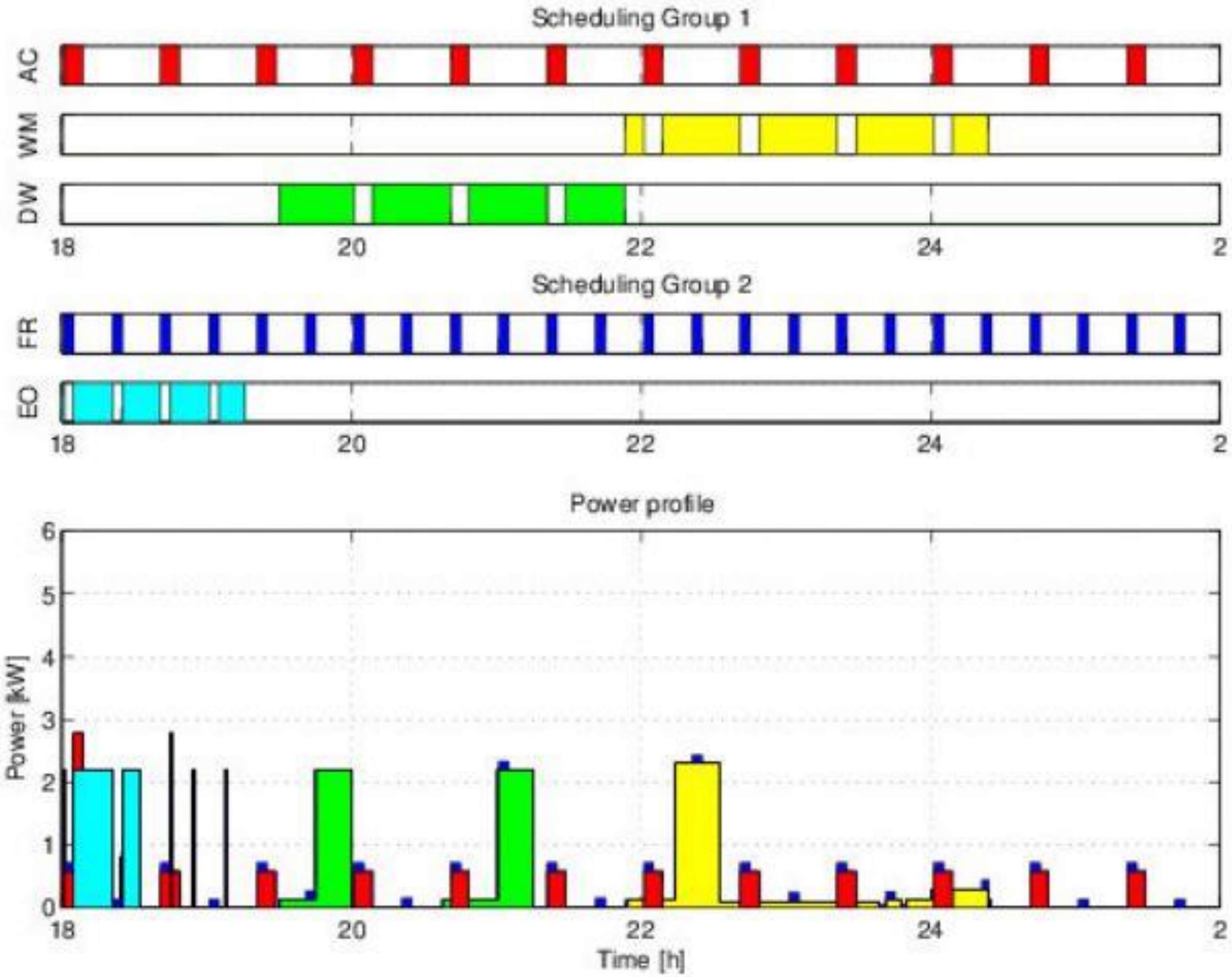


TABLE I. Load parameters. Loads are grouped according to the scheduling groups generated by the partitioned scheme.

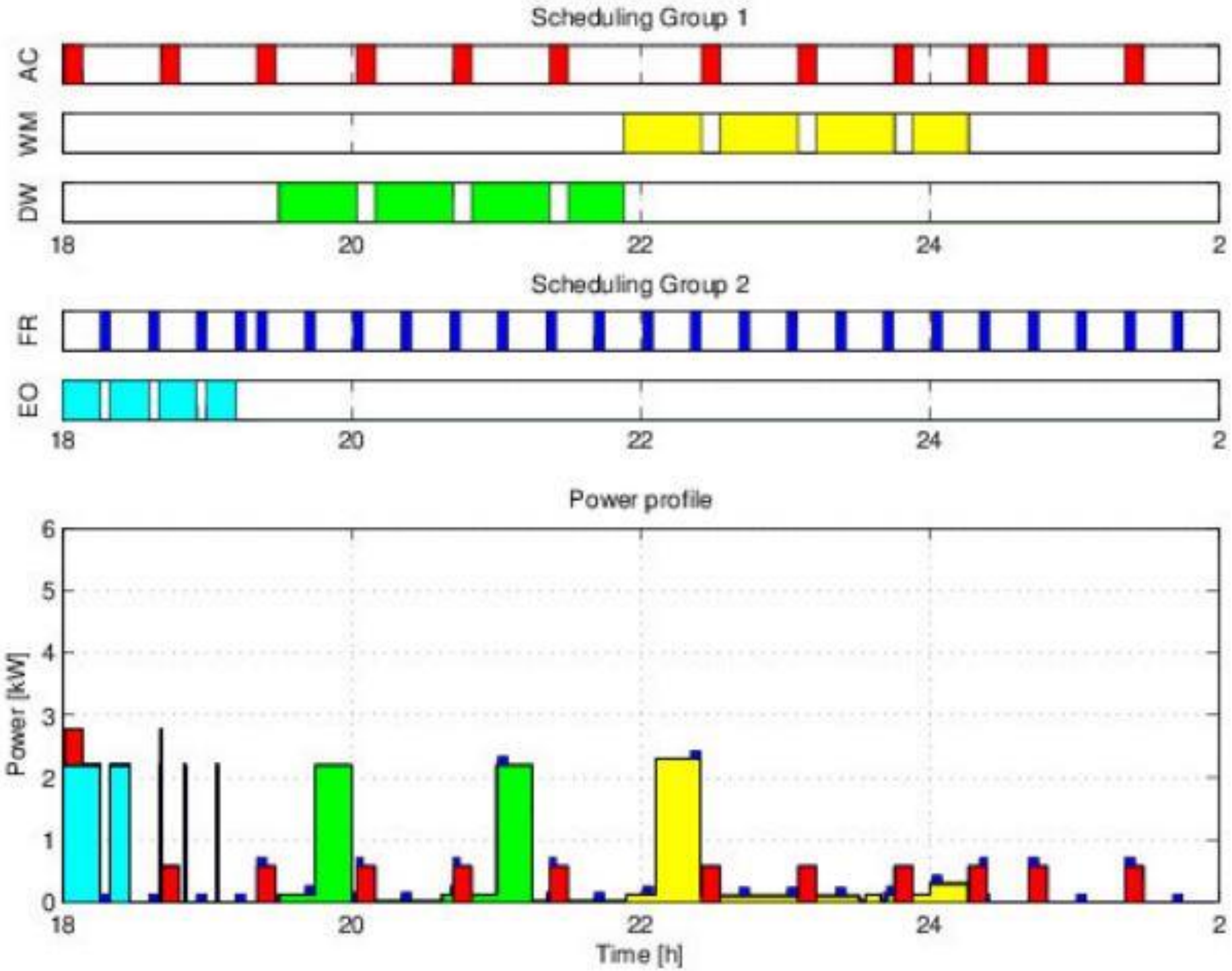
Load	P [W] power	T [s] period	C [s] activation time	b [s] non-preemptive chunk	r [hh:mm] request time	U utilization
AC	580	2402	456	456	–	0.19
WM	2300	21600	7200	1946	20:30	0.33
DW	2200	21600	7200	1946	19:30	0.33
FR	132	1201	241	241	–	0.20
EO	2200	4500	3600	960	18:00	0.80



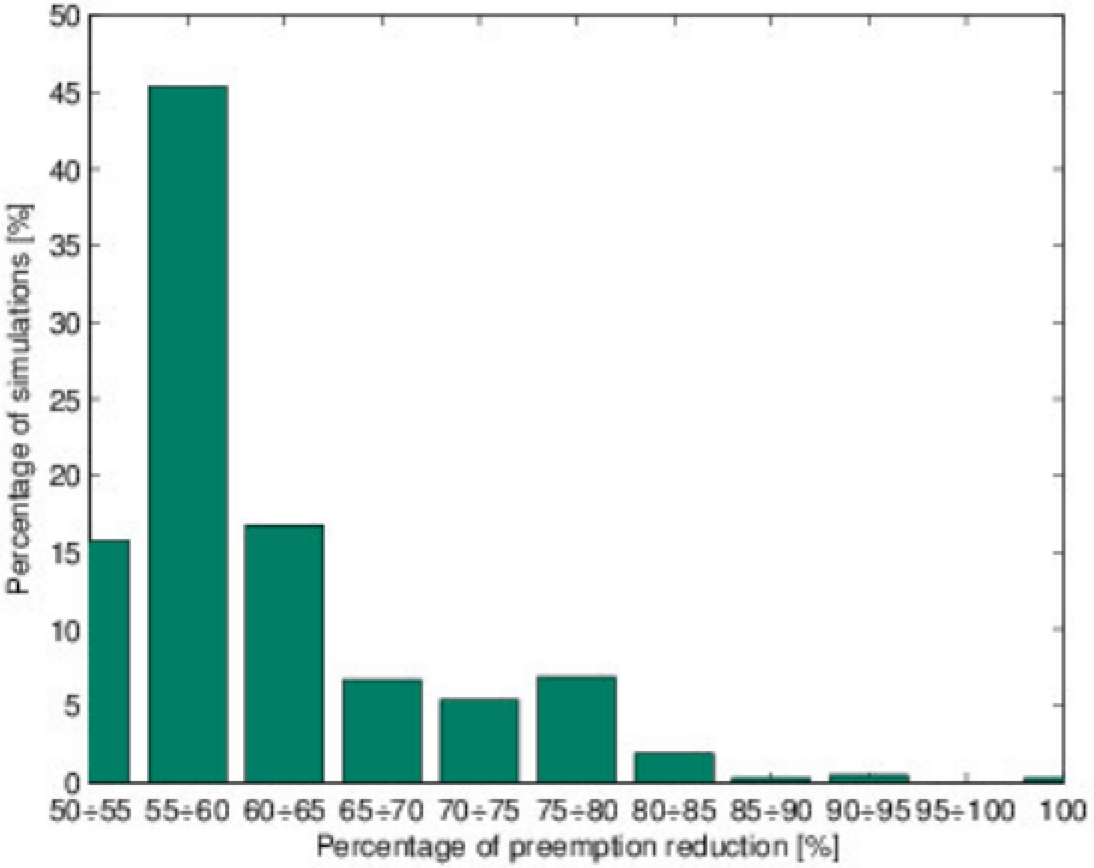
(a) No coordination



(b) Full-preemptive EDF



(c) Limited-preemptive EDF


0
5
10
15
20
25
30
35
40
45
50
Percentage of simulations [%]
50÷55
55÷60
60÷65
65÷70
70÷75
75÷80
80÷85
85÷90
90÷95
95÷100
100
Percentage of preemption reduction [%]

CONCLUSIONS

- The application of limited-preemptive scheduling allows to
    - Obtain a same peak load that in case of a full preemptive scheduling
    - Decrease the number of preemptions on each load
        - Thus reducing the negative impact of preemption on lifetime of appliances
    - Execute completely a task without interruption.
        - The task is placed completely in a non-preemptive chunk
    - The possibility to placed a non-preemptive chunk anywhere in the time does not cause failure of the system schedulability

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