APPENDIX TO
SCHEDULING MOLDABLE PARALLEL STREAMING TASKS ON HETEROGENEOUS PLATFORMS WITH FREQUENCY SCALING

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Computing Power Profiles and Deadlines

Holmbacka and Keller [2] measure the processor power consumption when executing the same instruction mix on all 4 cores of one core type. To compute the power consumption $Pow(f_k, i, j)$ attributable to a single core (for each frequency level, task type and core type), we subtract the base power ($P_{base} = 2.58\,W$) of the processor chip, i.e. the power consumed when the processor is switched on but idle, and divide by 4. When computing the energy consumption for scenario 1, we include the base power by adding $P_{base} \cdot M$. As M is fixed, this does not change the optimum solution.

In scenario 2 (minimize makespan, given energy budget), the energy consumption constraint must account for the processor's base power consumption:

$$E + T_{max} \cdot P_{base} \leq E_{max} .$$

Also in scenario 3 (minimize makespan, given average power budget), the energy constraint must include this:

$$E + T_{max} \cdot P_{base} \leq P_{avg} \cdot T_{max} .$$

As we might rewrite this as $E \leq (P_{avg} - P_{base})T_{max}$, i.e. we might interpret this as adapting the given power budget, the optimum solution is not affected.

We calculate the energy budget as the sum of all task energies and the base power for timespan M:

$$E_{max} = \sum_j \tau_j / f_k \cdot P_{avg}^{1.0} + P_{base} \cdot M ,$$

where $P_{avg}^{1.0}$ denotes the average over the power consumptions $P(f_k, i, j)$ over all task types i and core types j on frequency level $f_k = 1.0$ GHz. Deadline M is computed similarly to (5), only the factor is sharpened to 0.5.

Finally, average power budget is computed as

$$P_{avg} = p \cdot P_{avg}^{1.0}.$$

TABLE III
RESULTS FOR SCENARIO 2, RELATIVE TO TAP

scheduling	task set card.	makespan	energy	#budget transgr.
TAS	10	1.301	1.081	
	20	1.015	1.009	
	40	1.001	0.999	
	80	1.000	1.000	
	total	1.068	1.019	
TIP	10	1.533	1.158	4
	20	1.429	1.190	3
	40	1.377	1.148	2
	80	1.412	1.212	2
	total	1.438	1.177	11

Further Result Details

Tables III and IV give the detailed results for scenarios 2 and 3. Fig. 3 exemplary shows average makespan of TAS and TIP relative to TAP for each task set size in scenario 2.

ILP Details

Figure 4 summarizes all the (M)ILPs.

TABLE IV
RESULTS FOR SCENARIO 3, RELATIVE TO TAP

scheduling	task set card.	makespan	energy	av. power
TAS	10	1.155	1.077	0.945
	20	1.003	1.002	0.999
	40	1.000	1.000	1.000
	80	1.000	1.000	1.000
	total	1.039	1.020	0.986
TIP	10	1.369	1.059	0.787
	20	1.502	1.104	0.738
	40	1.507	1.183	0.791
	80	1.369	1.191	0.873
	total	1.437	1.134	0.797

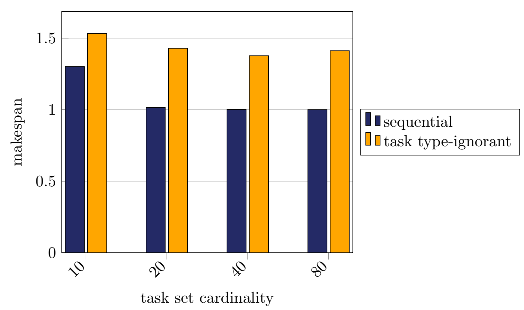

Fig. 3. Average makespan for sequential and task type-ignorant scheduling relative to average makespan for parallel scheduling in scenario 2

Variables:
binary $x_{i,j,k}$, $i = 1..2p-1$, $j = 1..n$, $k = 1..s$
real T_{max}

Minimize energy E for given deadline M
$\min E$
$\forall l:\ T_l \leq M$
Minimize makespan T_{max} for energy budget E_{max}
$\min T_{max}$
$\forall l:\ T_l \leq T_{max}$
$E \leq E_{max}$
Minimize makespan T_{max} for av. power budget P_{avg}
$\min T_{max}$
$\forall l:\ T_l \leq T_{max}$
$E \leq P_{avg} \cdot T_{max}$
Additional constraints for all targets
$\forall j:\ \sum_{i,k} x_{i,j,k} = 1$
$\forall j:\ \sum_{i:p_i > W_j} \sum_k x_{i,j,k} = 0$

Fig. 4. MILPs for different targets. E and T_l are given by (3) and (4).