Max-stretch minimization on an edge-cloud platform

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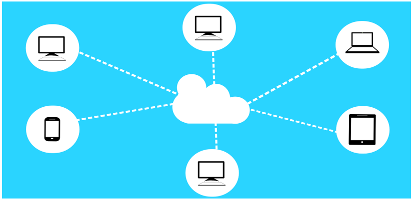
Introduction and motivation

Edge-Cloud computing:

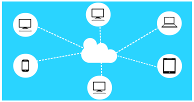
- Execute some jobs in-situ, directly on edge server where they originate from
- Delegate some jobs to a powerful cloud platform to avoid overloaded edge servers



For instance: smart radiators, mobile gaming, autonomous vehicles, flying drones, ...

Decide which job to communicate to the cloud platform

Objective function



- Response time (or flow time) for a job: time spent by that job in the system, starting from its release date and up to final completion
  $\rightarrow$ Classical objective: minimize maximum response time

- Stretch: response time normalized by job length
  $\rightarrow$ ensures fairness among jobs

- Two jobs released at same time, durations 1min / 10min, with long comm. time:
  Long job first $\rightarrow$ maximum stretch 11
  Short job first $\rightarrow$ maximum stretch 1.1
  Both cases $\rightarrow$ maximum response time 11

Framework

Two-level platform: P^c homogeneous processors in a cloud (speed 1), and P^e edge computing units (speed $s_j \leq 1$)

Independent jobs $J_1, \ldots, J_n$; For $1 \leq i \leq n$:

- o_i: origin processor on the edge ($1 \leq o_i \leq P^e$)
- w_i: amount of work required to complete the job
- r_i: release date
- up_i and dn_i: communication times required to send the job to the cloud and get the result back (uplink/downlink comms)

Processing times:

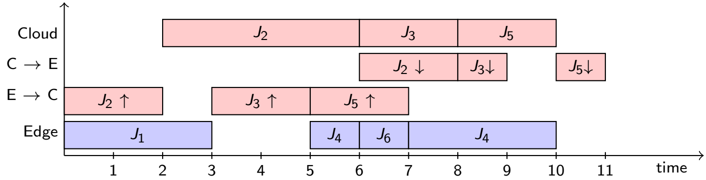
- $t_i^e = \frac{w_i}{s_{o_i}}$ on the edge
- $t_i^c = up_i + w_i + dn_i$ on the cloud

Preemption is possible, but not migration

An example

A single edge processor, with speed $\frac{1}{3}$, and six jobs:

J_1: $r_1 = 0$, $w_1 = 1$, $up_1 = dn_1 = 5$;
J_2: $r_2 = 0$, $w_2 = 4$, $up_2 = dn_2 = 2$;
J_3: $r_3 = 3$, $w_3 = 2$, $up_3 = 2$, $dn_3 = 1$;
J_4: $r_4 = 5$, $w_4 = 4/3$, $up_4 = dn_4 = 5$;
J_5: $r_5 = 5$, $w_5 = 2$, $up_5 = 2$, $dn_5 = 1$;
J_6: $r_6 = 6$, $w_6 = 1/3$, $up_6 = dn_6 = 5$.



Optimization problem

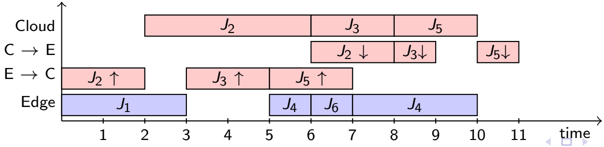
Goal: Minimize the maximum stretch:

- C_i: time at which execution of J_i is completed
- $S_i = \frac{C_i - r_i}{\min(t_i^e, t_i^c)}$
- $S_i = 1$ if job executed with minimum possible time
- Objective: Minimize $\max_{1 \leq i \leq n} S_i$

Constraints:

- Overlap computations and comms; full-duplex comm. channels
- Sequentialize comms involving a common processor

MinMaxStretch-EdgeCloud problem: Find a schedule that respects all constraints, with the aim of minimizing the max. stretch

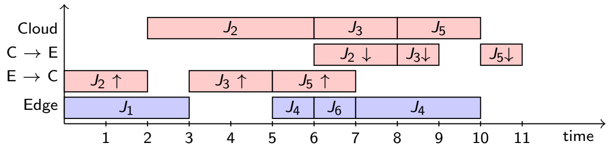


$S_2 = 1$

$S_3 = S_5 = \frac{6}{5}$

$S_1 = S_6 = 1$; $S_4 = \frac{5}{4}$

Online vs offline



$S_2 = 1$

$S_3 = S_5 = \frac{6}{5}$

$S_1 = S_6 = 1$; $S_4 = \frac{5}{4}$

Example: Decisions more difficult to take when there is no knowledge about jobs that will be released in the future

One could schedule job J_3 either on the edge or on the cloud: would complete at time 9 in both cases!

Depending on the jobs that come next (computation-intensive vs comm-intensive), one decision would be better than the other...

- Online case: problem where jobs are not known in advance
- Offline case: all job parameters are known in advance

We prove that the problem is NP-complete even in the offline case (see paper or long presentation), and we derive heuristics to address the general online problem

Heuristics

- Event-based algos: Reconsider decisions only when event occurs
- Polynomial-time algorithms, inspired from existing algorithms in the homogeneous case, but need to carefully choose proc. for each job

- *Edge-Only*: All jobs are executed locally on the edge
- *Greedy*: Schedules first the job that would currently achieve the highest stretch
- *SRPT*: Builds on classical SRPT strategy, i.e., assigns to a processing unit the job that it can finish the earliest
- *SSF-EDF*: Set a target stretch, give priorities to job according to deadlines, execute highest priority job on processor that minimizes its stretch

Simulations

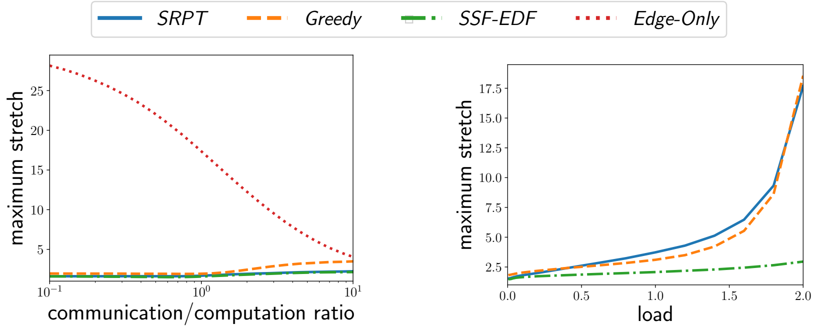
- Implementation of simulation tool and heuristics in C++
- Use of parameters from real edge-cloud platforms

- Random instances: 20 cloud processors, 10 slow edge processors with speed $s = 0.1$, and 10 fast edge processors with speed $s = 0.5$; jobs generated using a uniform distribution for the execution and communication times, as well as the release date and the origin processor; CCRs ranging from 0.1 (compute-intensive scenario) to 10 (communication-intensive scenario)

- Kang instances: different types of edge processors, depending on whether their computational unit is a GPU or a CPU, and their communication channel is 3G, LTE, or Wi-Fi; jobs created according to these values.

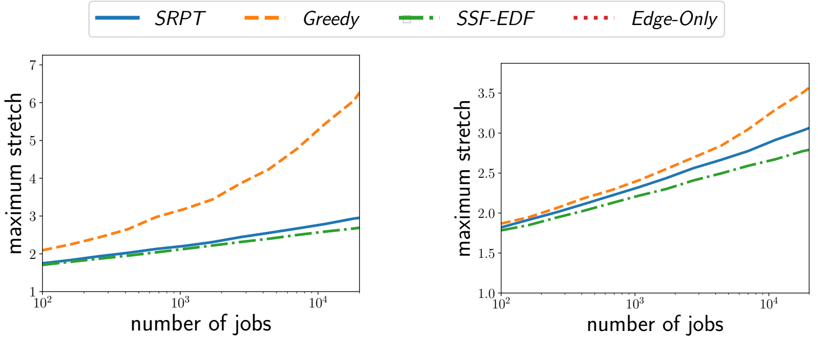
`github.com/Redouane-Elghazi/Max-Stretch-Minimization-on-an-Edge-Cloud-Platform.git`

Results: Random instances



- *Load: Average number of jobs originating from edge, simultaneously in the system (default load = 0.05, default CCR=1)*
- New heuristics much better than *Edge-Only* for small CCRs
- *SSF-EDF* is the best in all scenarios, *SRPT* very close for small loads
- *Greedy* slightly behind, *SRPT* and *Greedy* do not scale well with load

Results: Kang instances



20 edge proc. and 10 cloud proc. 100 edge proc. and 10 cloud proc.

- CCR dictated by platform parameters
- *SSF-EDF*, closely followed by *SRPT*, is clearly the best
- *Edge-Only* cannot keep up when the number of jobs increases

Trade-off: Solution quality vs execution time

The different algorithms may be useful in different situations:

- Note that all heuristics do not exceed a few seconds
- *SSF-EDF* gives the best solutions overall, but is the most costly
- *SRPT* is easier to implement and it is the fastest, very close to *SSF-EDF* with reasonable load
- *Greedy* can be better than *SRPT* with high loads, but more costly
- *Edge-Only*: costly solution that does not exploit the cloud
- Importance of using cloud resources when available, in particular when communication costs are not too important

Conclusion

Problem of scheduling independent jobs on an edge-cloud platform:

- Design of general model with realistic communication model
- Minimizing the *maximum stretch* is NP-complete, even without release dates and on a homogeneous platform
- Design of heuristic algorithms in online setting
- Algorithms delegating jobs to cloud much better than *Edge-Only*
- *SSF-EDF* very efficient, *SRPT* is an interesting (cheaper) alternative

Future work:

- Derive theoretical bounds for online algorithms (competitive results), for instance for some specific job distributions
- Address more complicated framework where cloud processors are not available full-time