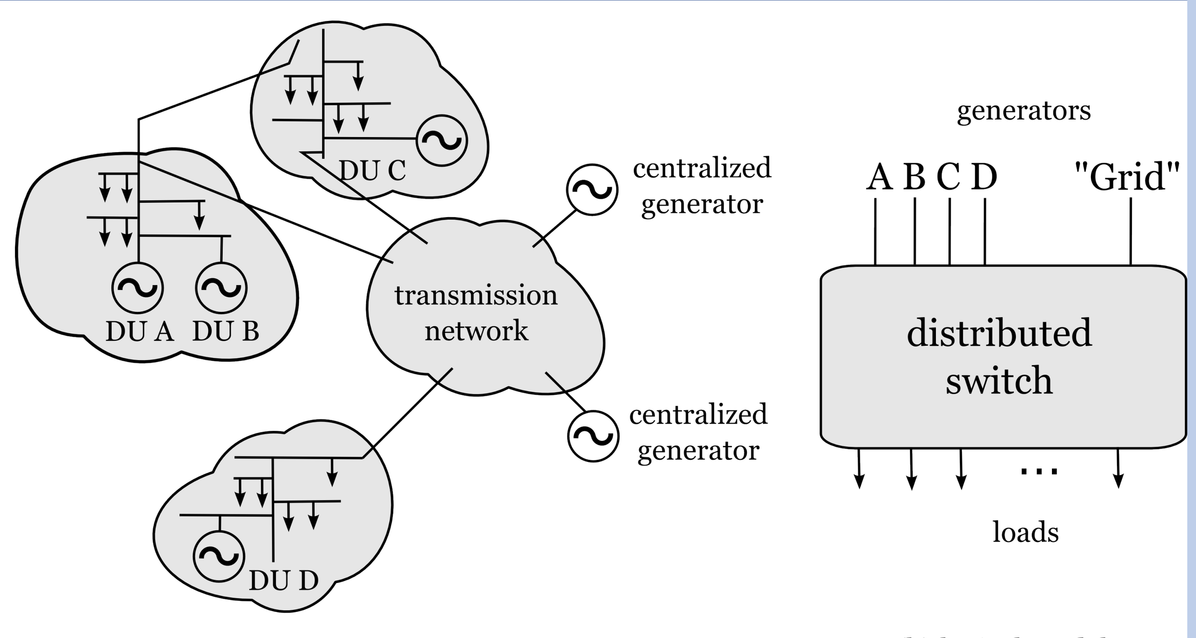
Efficient Demand Assignment in Multi-Connected Microgrids with a Shared Central Grid

Kirill Kogan[1], Sergey Nikolenko[2,3,4], Srinivasan Keshav[1], Alejandro López-Ortiz[1]

[1]University of Waterloo, Canada
[2]National Research University Higher School of Economics, St. Petersburg, Russia
[3]Steklov Mathematical Institute, St. Petersburg, Russia
[4]St. Petersburg Academic University, Russia

Physical Infrastructure



(a) physical connectivity (b) logical model

The physical infrastructure in (a) is represented logically in (b). Note that "Grid" represents all centralized generators available through the transmission network. The "distributed switch" refers to the set of switches in microgrids that determines how loads are matched to generators.

Motivation

- local electricity generation already supplements centralized distribution in many developing countries with less-than-adequate central grids [1];
- in developed countries, local generation may still be cheaper, greener, or both;
- in the future, microgrids will opportunistically form connections with each other to increase reliability;
- this leads to the concept of "packetized" electricity [2, 3], where demands are represented as "data packets", and power distribution becomes similar to packet scheduling in a rearrangeable switch [4];
- the world's first electricity switch with packets of electricity has already been designed [5].

Our Goals and Contributions

- we consider efficient demand satisfaction in multi-connected microgrids, where a demand can be met by different generation resources;
- for each demand, a *load balancing vector* determines which generators are connected/available to satisfy it;
- in our present model, each load balancing vector allows the central grid plus one more generator;
- we concentrate on scheduling *elastic non-preemptive* demands [6]: demands that can be delayed for a while but cannot be preempted while servicing;
- thus, we minimize the delay in satisfying a set of resource demands and the total number of configurations (rearrangements in the switch);
- we build a systematic study of these online policies and explore the impact of various parameters of scheduling policies on objective functions.

Simplifying Assumptions

- all generators have the same cost of power;
- distribution losses are negligible;
- there is a non-negligible penalty on switching called *configuration overhead*;
- demands are elastic and non-preemptive, i.e., it is possible (though undesirable) to delay a demand;
- a demand cannot be split, it has to be satisfied from a single source;
- each demand's load balancing vector has one shared port (central grid) and one other port available for this demand.

Notation and Problem Statement

Given a switching system $(I, \mathcal{D})$:

- each input has capacity c_i;
- each demand d has length $l(d)$, width $w(d)$, and load-balancing vector $v(d)$;
- time is slotted;
- a schedule P is a sequence of configurations; the length of a configuration C is defined by the longest demand that is scheduled during C;
- there is a configuration overhead of V time slots between two consecutive configurations.

The objective is to satisfy loads in $\mathcal{D}$ as fast as possible, in terms of either the number of configurations or their total length.

Parameters of Scheduling Policies

Four important parameters define the behaviour of a scheduling policy:

- input port capacities;
- demand lengths;
- demand widths;
- "normalized load".

General Greedy Policies

GreedySchedulingPolicy($\mathcal{D}$, I)

$D := \mathcal{D}$, $\mathcal{C} := \emptyset$.
while $D \neq \emptyset$ **do**
  start new configuration $C := \emptyset$, $I' := I$;
  while there are available ports and demands **do**
    $(i, d) :=$ ChoosePortDemand(D, I');
    $C := C \cup \{(i, d)\}$, $c'_i := c'_i - w(d)$, $D := D \setminus \{d\}$;
  $\mathcal{C} := \mathcal{C} \cup \{C\}$, $D := D \setminus \{d \mid d \in C\}$.
Return $\mathcal{C}$.

SG (Shared Greedy)

function ChoosePortDemand($\{\mathcal{D}_i\}_i$, I)
  for $i := 2$ **to** I **do**
    if $c_i > w(d)$ for some $d \in \mathcal{D}_i$ **then**
      return $(i,$ ChooseDemand$(\mathcal{D}_i, c_i))$;
  Return $(1,$ ChooseFirst$(\{\mathcal{D}_i\}_i, I))$.

Shared Longest Demand

SLD

function ChooseDemand($\mathcal{D}_i, c_i$)
  Return arg max $\{l(d) \mid d \in \mathcal{D}_i\}$.
function ChooseFirst($\mathcal{D} = \{\mathcal{D}_i\}_i, I$)
  Return arg $\max_{d \in D} l(d)$.

Shared Longest Port

SLP

function ChooseDemand($\mathcal{D}_i, c_i$)
  Return arg max $\{l(d) \mid d \in \mathcal{D}_i\}$.
function ChooseFirst($\mathcal{D} = \{\mathcal{D}_i\}_i, I$)
  Return $d \in$ arg $\max_{\mathcal{D}_j} k(\mathcal{D}_j)$.

Shared Best Product

SBP

function ChooseDemand($\mathcal{D}_i, c_i$)
  Return arg max $\{l(d) \mid d \in \mathcal{D}_i\}$.
function ChooseFirst($\mathcal{D} = \{\mathcal{D}_i\}_i, I$)
  Return arg $\max_{(i,d)} \{k(\mathcal{D}_i) * l(d)\}$.

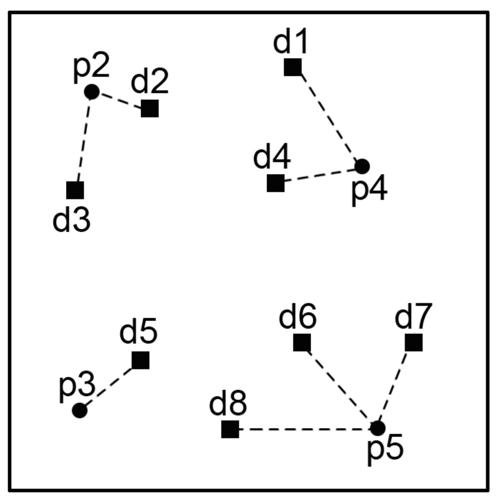
Our Results

In the theoretical study, we concentrated on competitive analysis, proving lower and upper bounds on the ratio between optimal and the current algorithm's objective value. Two special cases: unit capacities and unit widths of the demands.

ALG	Unit capacities		Unit widths		General
	Lower	Upper	Lower	Upper	Upper
SG	1	3/2	5/3	2	4
SLD	$3/2 - 1/2^{l-1}$	3/2	5/3	2	4
SLP	1	1	1	1	2

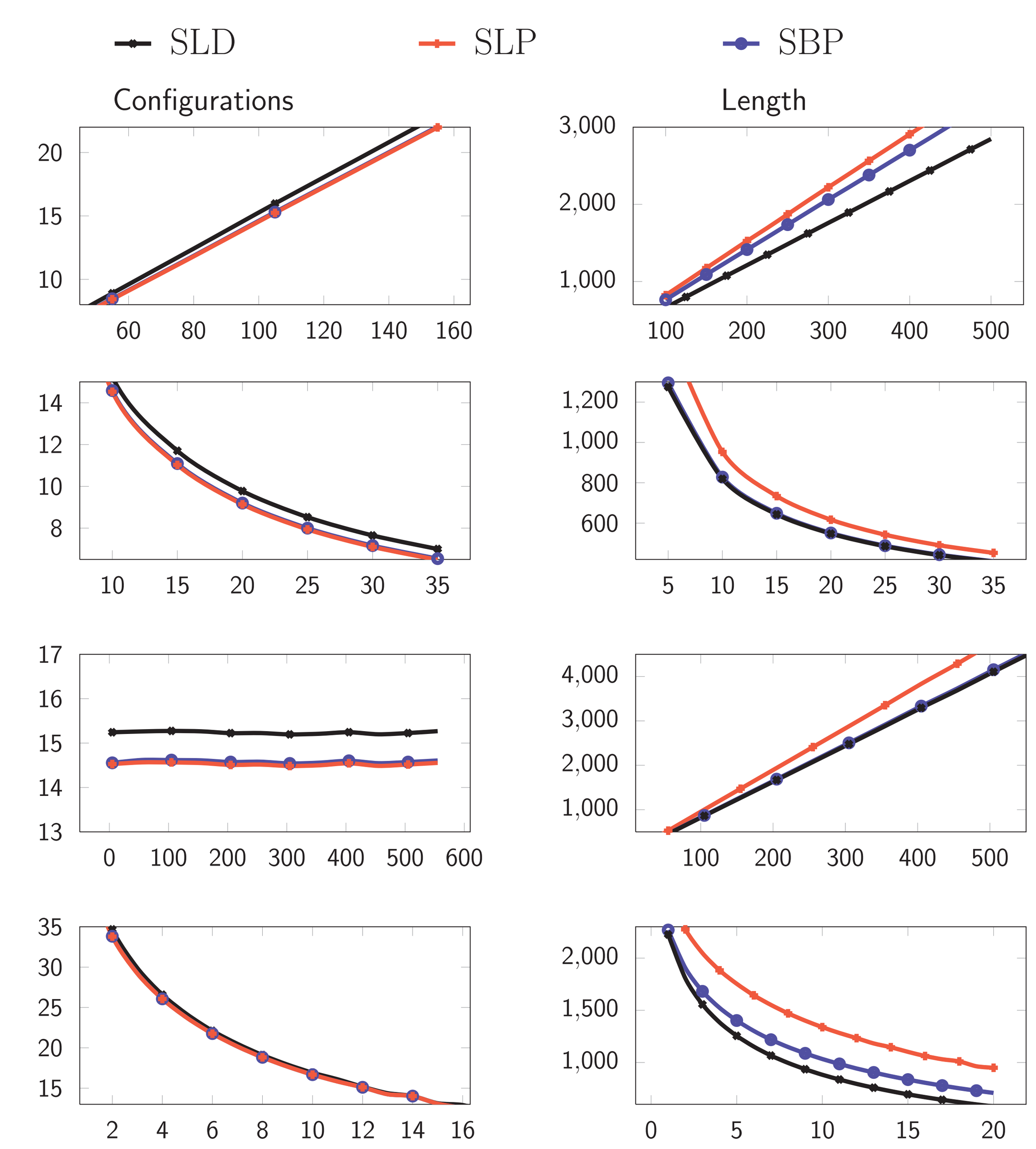
Table: Theoretical results summary.

Input Generation



In the simulations, we generated inputs on the unit square. In this case, there are five input ports: p_1, p_2, p_3, p_4, and p_5; $\mathcal{D}_2 = \{d_2, d_3\}$, $\mathcal{D}_3 = \{d_5\}$, $\mathcal{D}_4 = \{d_1, d_4\}$, and $\mathcal{D}_5 = \{d_6, d_7, d_8\}$. Each demand has p_1 (central grid) and the nearest other port in its load balancing vector.

Simulations



Simulation study; y-axis, avg. no. of configs (left) and avg. total length (right); x-axis, top to bottom: no. of demands d; no. of ports p; max length L; shared port capacity c_1.

Further Work

- a natural generalization to the case of arbitrary load balancing vectors;
- scheduling in economic constraints, with costs entering the picture;
- a more practical simulation study on real data (if such data for microgrids becomes available).

References

- S. Biswas, "India struggles to deliver enough power," 2012. [Online]. Available: http://www.bbc.co.uk/news/world-asia-india-19063241
- H. Saitoh and J. Toyoda, "A new concept of electric power network for the effective transportation of small power of dispersed generation plants," *IEEE J. Trans. PE*, vol. 115, no. 6, pp. 568–575, 1995.
- R. Abe, H. Taoka, and D. McQuilkin, "Digital grid: Communicative electrical grids of the future," *IEEE Trans. Smart Grid*, vol. 2, no. 2, pp. 399–410, 2011.
- A. Kesselman and K. Kogan, "Nonpreemptive scheduling of optical switches," *IEEE Transactions on Communications*, vol. 55, no. 6, pp. 1212–1219, 2007.
- "World's first digital grid router controls electricity packets, boosts grid access for renewables in Japan," 2013. [Online]. Available: http://www.japanfs.org/en/pages/032474.html
- S. Keshav and C. Rosenberg, "On load elasticity," in *Proc. IEEE COMSOC MMTC E-Letter*, To Appear.

Mail: snikolenko@gmail.com, sergey@logic.pdmi.ras.ru

More info at: http://blizzard.cs.uwaterloo.ca/iss4e/