Coordination of autonomic mechanisms in communications networks

Richard Combes ([1]), Zwi Altman ([2]) and Eitan Altman ([3])

[1]KTH, The Royal Institute of Technology
[2]Orange Labs
[3]INRIA

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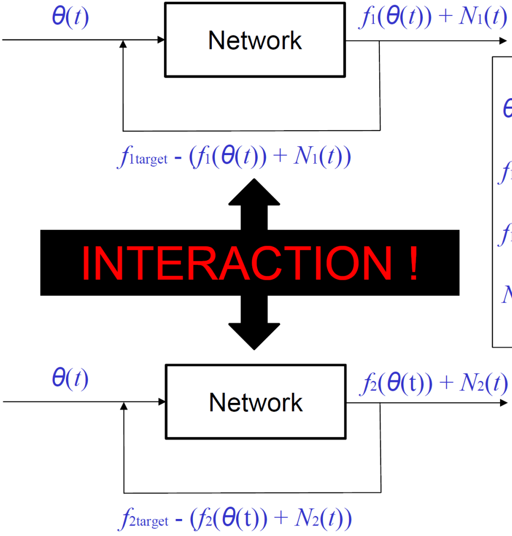
SON mechanisms in parallel

- A SON (Self-Organizing Network) function is an entity which adjusts a performance indicator by controlling a network parameter.
- SONs are designed as stand-alone functions, but run in parallel. A good coordination mechanism is needed.

Use case	Parameters	Performance indicators
Interference Management	Transmitted powers	Network capacity, blocking/outage rate cell-edge throughput
Load balancing	Pilot powers Handover margins	Network capacity, blocking/outage rate cell-edge throughput
Mobility robustness	Handover margins, time-to-trigger	Dropped call rate, radio link failures
Energy savings	Transmitted powers BS deactivation	Energy consumption

Control loops



$\theta(t)=(\theta_1(t),\theta_2(t))$	: Parameters
$f_1(\theta(t))$, $f_2(\theta(t))$	: KPIs
$f_{1\text{target}}$, $f_{2\text{target}}$	: KPIs targets
$N_1(t)$, $N_2(t)$	: Noise

The model

Each SON is represented by an update equation:

$$\theta_i^\epsilon[t+1] = \theta_i^\epsilon[t] + \epsilon\left(F_i(\theta[t]) + N_i[t]\right),$$
$$F_i(\theta) = \overline{f}_i - f_i(\theta).$$

- $\epsilon > 0$: small step size
- t: time (discrete)
- $\theta_i^\epsilon[t]$: i-th parameter at time t
- $f_i(\theta)$: i-th performance indicator
- $\overline{f}_i$: target for i-th performance indicator
- $N_i[t]$ measurement noise (for instance i.i.d with zero mean).

Reduction to a linear ODE

- Associated ODE (Ordinary Differential Equation):

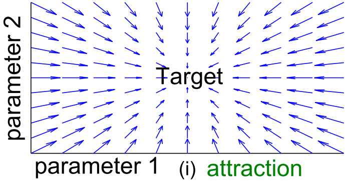
$$\dot{\theta}_i = F_i(\theta).$$

- Stochastic approximation: the distribution of $\theta^\epsilon[t]$, $\epsilon \to 0^+$, $t\epsilon \to +\infty$ is concentrated on sets which are *attracting* and *asymptotically stable* for the ODE.
- Linearization around a stationary point, $F(\theta_0) = 0$:

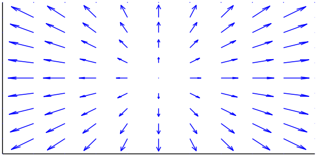
$$\dot{\theta} \approx A(\theta - \theta_0)\ ,\ \ A = JF(\theta_0).$$

- Grossman-Hartman theorem: both ODEs have the same *qualitative behavior* (convergence/divergence ...) near fixed points. We consider linear ODEs here.

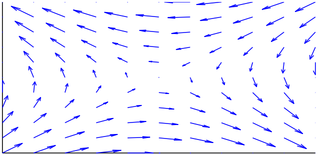
Linear ODEs in 2 dimensions



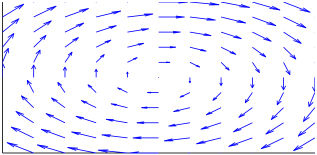
(i) attraction



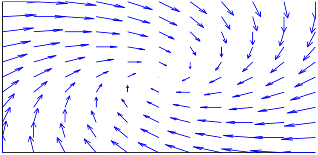
(ii) repulsion



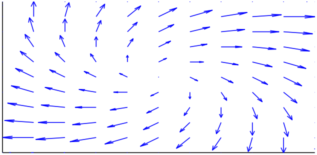
(iii) saddle point



(iv) vortex



(v) attractive vortex



(vi) repelling vortex

The coordination problem

- Linear transformation:

$$\dot{\theta} = A\theta \text{ (original ODE)}$$
$$\dot{\theta} = CA\theta \text{ (transformed ODE)}.$$

- Goal: find a matrix C with certain properties such that the transformed ODE converges to 0 ($\{0\}$ is an asymptotically stable attractor).
- Interesting properties:
  - (convergence speed): CA has a small condition number,
  - (fully distributed coordination): C is diagonal,
  - (sparsity) $C_{j,i} = 0$ if $A_{i,j} = 0$,
  - (architecture constraints) $C \in \mathcal{C}$ with $\mathcal{C}$ a convex set.

Coordination as a semi-definite program

- The coordination problem can be written as a SDP (semi-definite program):

$$\begin{aligned} &\text{maximize } G(CA) \\ &\text{subject to } C \in \mathcal{C} \\ &\qquad \text{and } \exists X\,,\ 0 \prec X\,,\ (CA)^T X + XCA \prec 0. \end{aligned}$$

- There are good SDP solvers: the coordination problem is not computationally difficult

Fully distributed coordination

- Fully distributed coordination, no information exchange between SONs: C is *diagonal*.
- In dimension 2, there always exists such a matrix, for instance:

$$C = \begin{pmatrix} 1 & 0 \\ 0 & \underline{+}\delta \end{pmatrix} \;,\; \delta = o(1)$$

- In dimension 3, a matrix exists iff : A^{-1} has a non-zero diagonal element, e.g:

$$C = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \underline{+}\delta & 0 \\ 0 & 0 & \underline{+}\delta \end{pmatrix} \;,\; \delta = o(1)$$

- For arbitrary dimension: open problem, no simple characterization

Distributed coordination for sparse matrices

- SON i does not influence j if $A_{i,j} = 0$,
- In practice, there is a large number of SONs, but each SON interacts with only a few others: A can be very sparse, e.g:

$$\begin{pmatrix} a_{1,1} & a_{1,2} & 0 & 0 \\ 0 & a_{2,2} & a_{2,3} & 0 \\ 0 & a_{3,2} & a_{3,3} & 0 \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix}$$

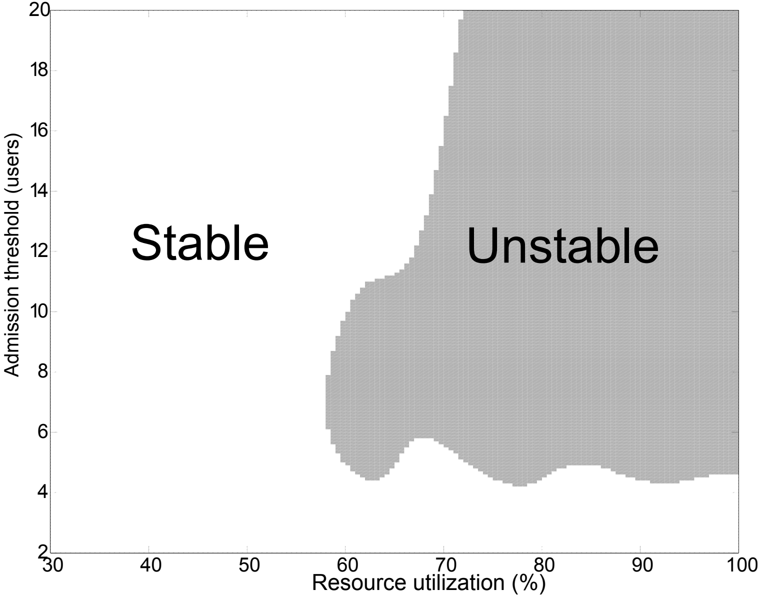
- SONs which do not interact should not exchange information: $C_{j,i} = 0$ if $A_{i,j} = 0$.
- Simple solution: $C = -A^T$, since $-AA^T$ is a Hurwitz matrix.

An example: resource allocation and admission control

- Single base station, downlink, 2 SONs
- Users enter the network as a Poisson process, to download a file of mean size $E[\sigma]$, with data rate R_0.
- Bandwidth is shared fairly between active users (processor sharing)
- SON 1: Ressource allocation, the station uses $x \in [0, x_{max}]$ resources to achieve a target *outage rate*
- SON 2: Admission control, the station adjusts the maximal number of active users β (blocking threshold) to achieve a target *file transfer time*
- The stationary distribution of the number of active users can be calculated in closed form (by reversibility)

$$\pi(n, x, \beta) = \frac{\rho(x)^n \prod_{k=0}^{n-1} \phi(k - \beta)}{\sum_{n \geq 0} \rho(x)^n \prod_{k=0}^{n-1} \phi(k - \beta)}.$$

Stability without coordination



Conclusion

- Generic framework for coordinating SONs, as opposed to the current ad-hoc approach
- Even in simple examples (2 SONs, 1 base station), instability occurs
- Same conclusions for power control SONs (see paper)
- In small dimensions, distributed coordination is well understood
- There exists simple sparse coordination schemes

Questions ?

Thank you for your attention, any questions ?