TREC 2008-2011

F. Baccelli

INRIA & ENS

EVALUATION INRIA, MARCH 2012

SUMMARY

I General Framework

II Dynamics: Two Flowers

III Geometry

1 Discrete: Garden and Flowers

2 Euclidean: Garden and Flowers

IV Future

More Gardens & Flowers in private presentation!

I. FRAMEWORK FOR TREC

- **THEORIE DES RESEAUX ET COMMUNICATIONS**
  - **EPI of INRIA Paris–Rocquencourt since 2001**
  - **Two Interfaces**
    - **Département d'Informatique of Ecole Normale Supérieure Paris since 2001**
    - **LINCS laboratory since 2011.**
- **Permanent Staff:**
  F.B., B. Blaszczyszyn, A. Bouillard [ENS], A. Bušić, M. Lelarge.

I. TREC: RESEARCH DIRECTIONS [07,12]

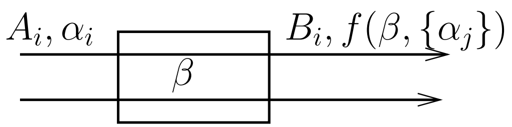
- **Three main research directions interfacing Mathematics and Communications**
  - **Network dynamics II**
  - **Network geometry III**
    1. **Discrete: Random graphs**
    2. **Euclidean: Stochastic geometry**

II. NETWORK DYNAMICS

- **Initial domain of TREC: queuing, stochastic networks, (max,plus), control.**
- **Evolution thanks to the hiring of Ana Bušić [INRIA 09] and Anne Bouillard [ENS, 10]**
- **Research**
  - **Network Calculus,** $\Uparrow$ **Thesis of A. Junier**
  - **Simulation,** $\Uparrow$
  - **Control,** $\Leftrightarrow$ **Thesis of G. Carofiglio**
  - **Inverse Problems in Queuing,** $\Downarrow$ **Thesis of B. Kauffmann**
- **More on Garden in the private session**

II. FLOWER 1: Exact Worst-Case Performance Bounds

Network calculus: computing guaranteed performance bounds in networks based on the (min,plus) algebra and on flow constraints.

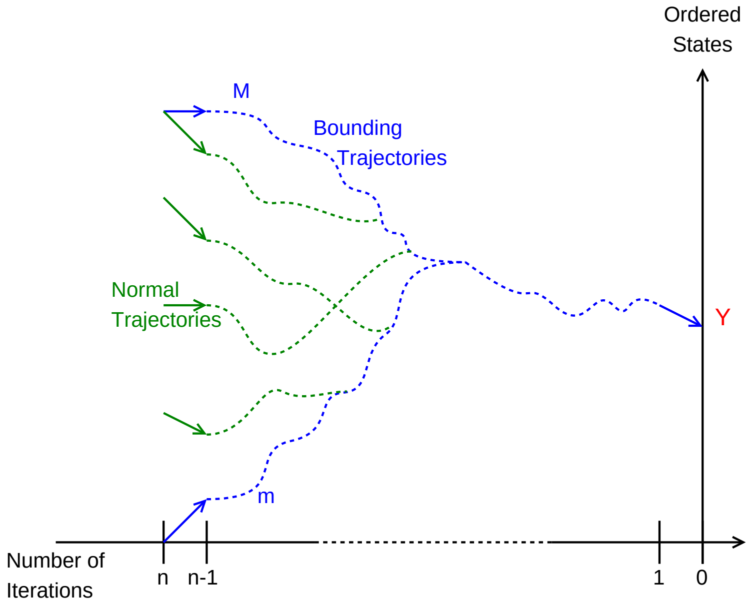


(min,plus) algebra $\rightarrow$ over-pessimistic
linear programming $\rightarrow$ achievable bounds

- **tandem networks: polynomial algorithm;**
- **feed-forward networks: NP-hard problem.**

A. Bouillard, L. Jouhet and E. Thierry, INFOCOM 10

II. FLOWER 2: Perfect Simulation



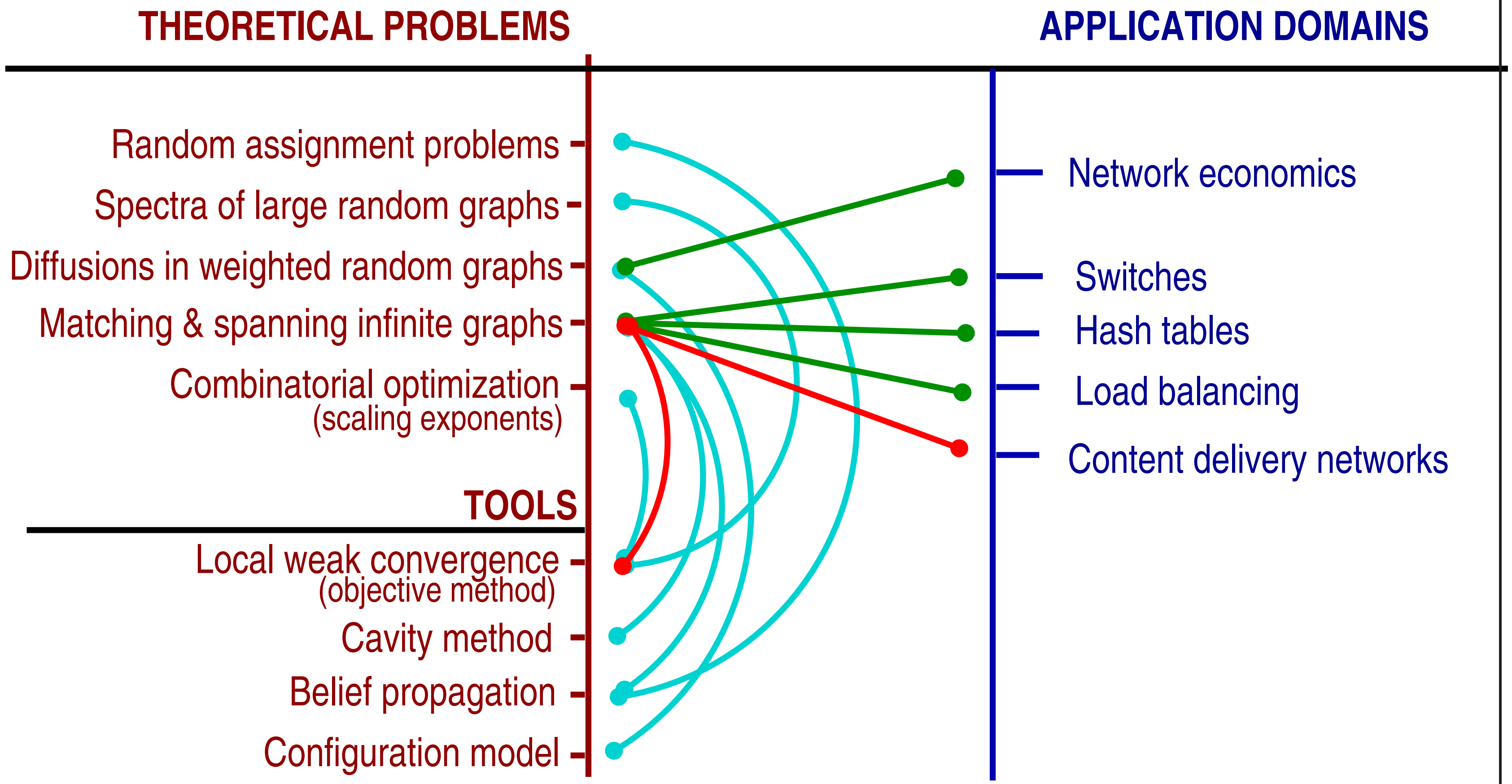
- **Coupling from the past: provides unbiased samples of the stationary distribution of an ergodic Markov chain.**
- **Envelope Perfect Sampling: non-monotone case.**
- **Detection of and bounds on the coupling time.**

A. Bušić, B. Gaujal and F. Pin, Performance Evaluation 12

III.1. DISCRETE GEOMETRY: RANDOM GRAPHS

- **Garden: analysis of random choices in graphs/networks:**
  - **statistical variations**
  - **decentralized algorithms**
- **Example of problem: Maximum Matchings:**
  - **combinatorial structure capturing the constraints.**
  - **size of matching: throughput (switches), critical load (hash tables), minimal overload (CDN).**
- **Example of method: Cavity Method:**
  - **inspired from statistical physics.**
  - **associated with message passing algorithms: belief propagation.**

III.1. DISCRETE GEOMETRY: RANDOM GRAPHS (*continued*)



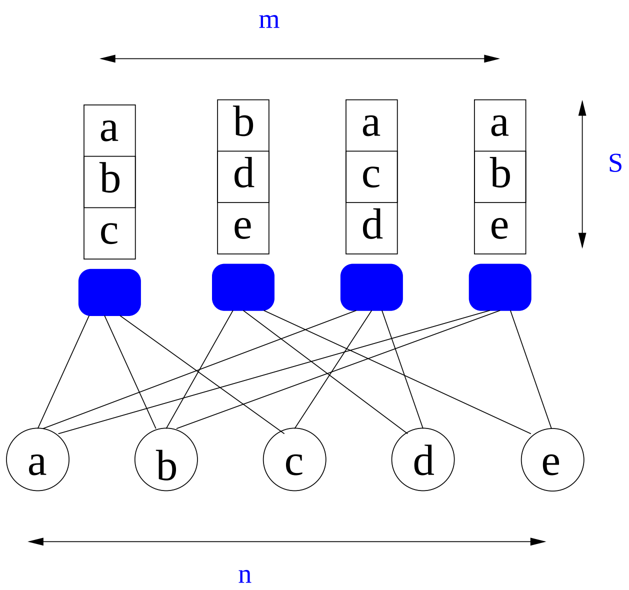
III.1. A MATH RESULT
CONTINUITY UNDER LOCAL CONVERGENCE

- **When does local geometry characterize global structure?**
- **Matching number ν of a sequence of graphs G_n with uniform distribution given their degree distribution ϕ:**

$$\frac{\nu(\mathbf{G_n})}{\mathbf{n}} \rightarrow_{\mathbf{n}\rightarrow\infty} \mathbf{M}(\phi).$$

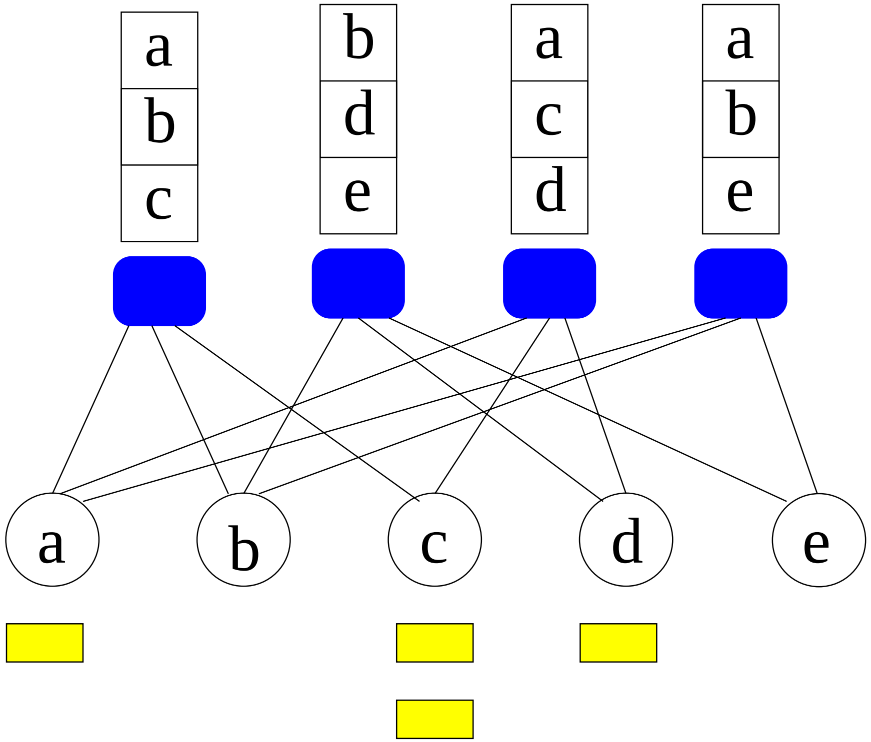
Thesis of J. Salez

FLOWER 3: CONTENT DISTRIBUTION NETWORKS A BIPARTITE GRAPH MATCHING REPRESENTATION



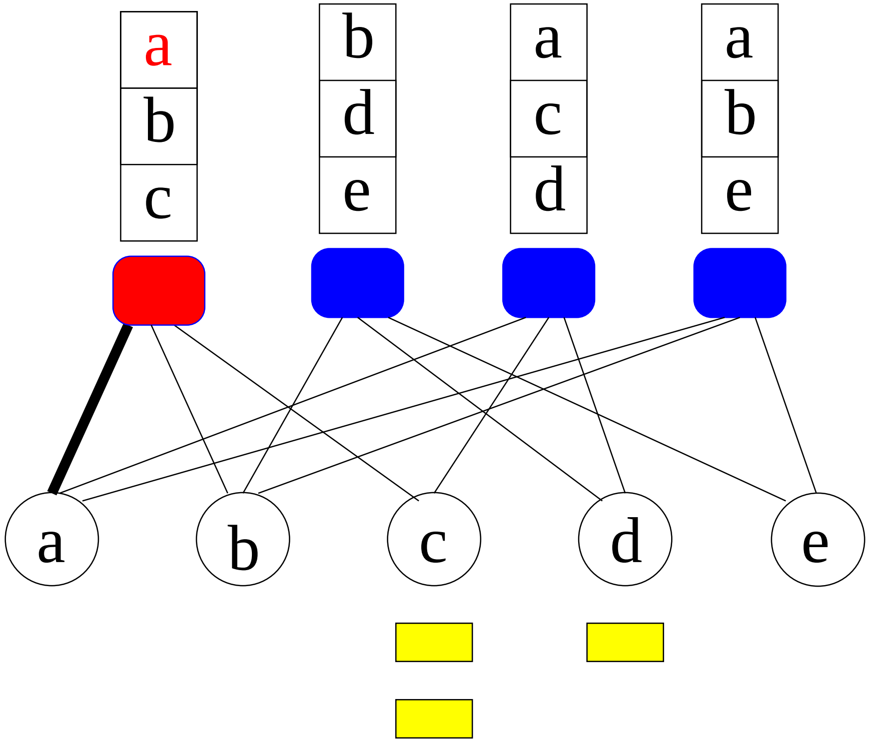
- n **contents**
- m **servers, each storing** S **contents sampled independently (but not uniformly).**
- **degree of a content: number of replicas for this content in the system.**

F3: ONLINE MATCHING ALGORITHM

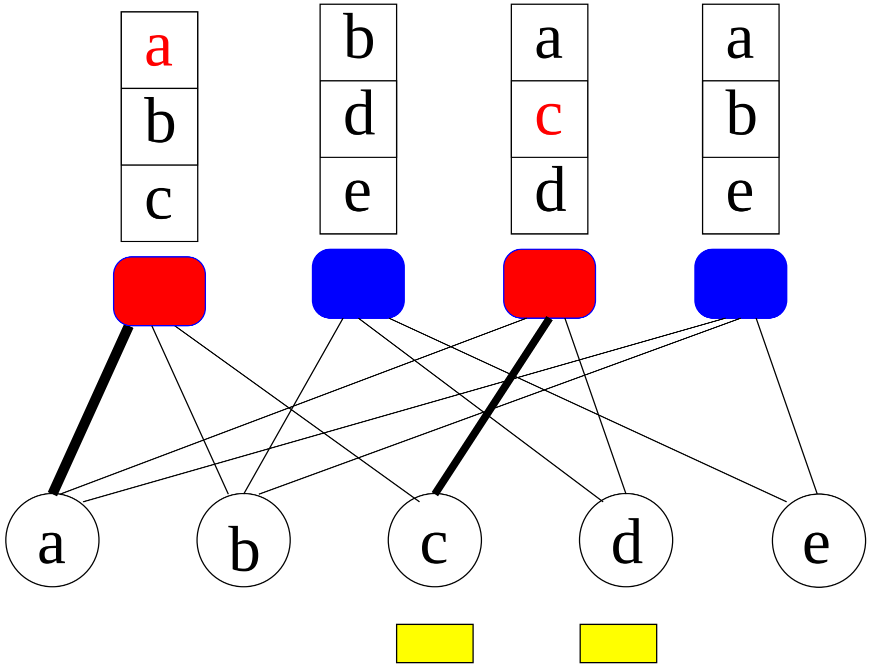


Adding requests for contents.

F3: ONLINE MATCHING ALGORITHM



F3: ONLINE MATCHING ALGORITHM



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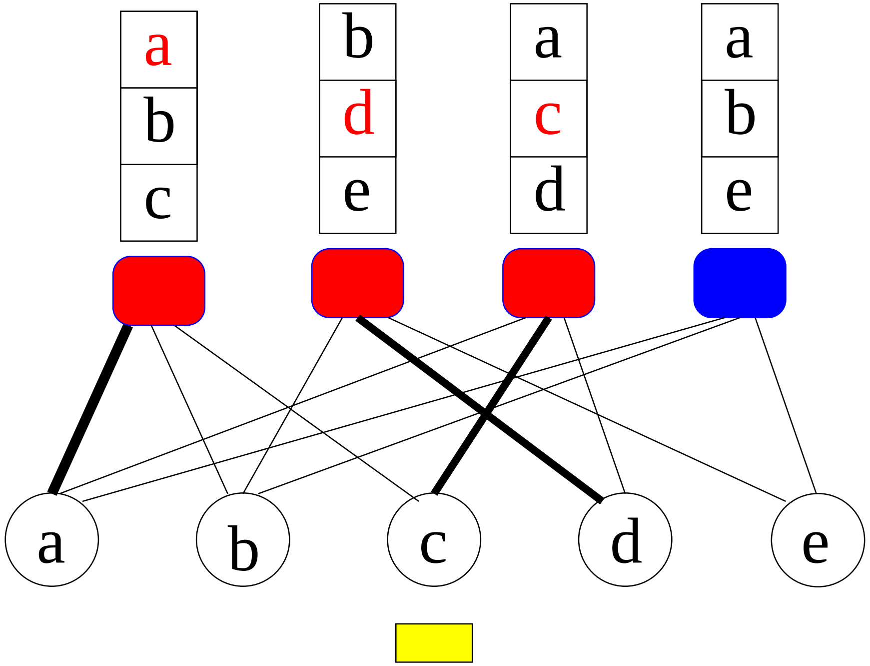
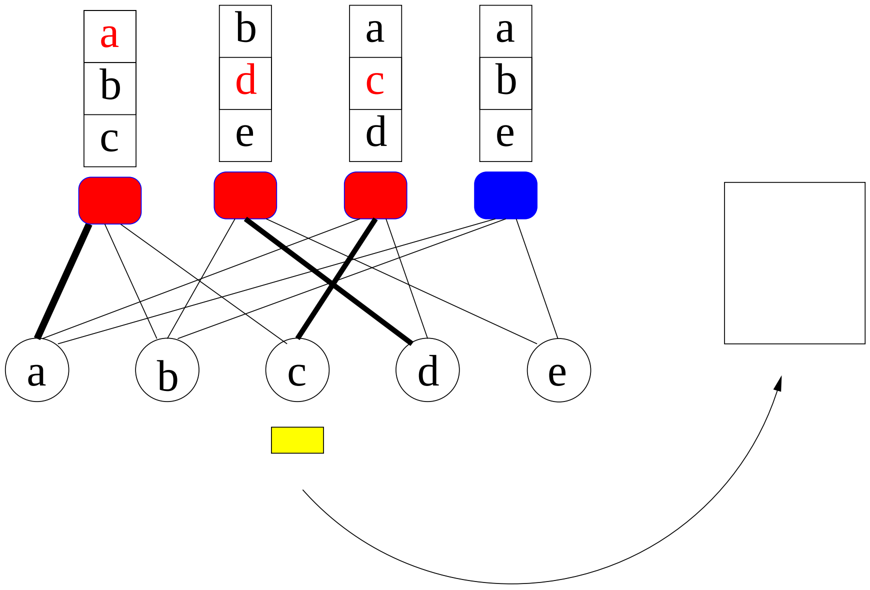


F3: ONLINE MATCHING ALGORITHM



Q: How to choose the number β_i of replicas for each type i of content depending on its popularity?

F3 RESULTS: OPTIMAL ALLOCATION WITH HETEROGENEOUS LOADS

- **Static Case: Minimizing Inefficiency:**
  - **Underloaded regime: uniform replication,** $\beta_i = \beta$.
  - **Overloaded regime: most popular class** i^* **only,** $\beta_i = 0, \ \forall i \neq i^*$.
  - **Critical regime: equalizing all** β_i **for** $i \neq i^*$.

  M. Leconte, M. Lelarge and L. Massoulié, SIGMETRICS 2012.

- **Queuing/Matching problem also studied by**

A. Bušić and V. Gupta and J. Mairesse, Under Revision J. Appl. Prob.

III.1. COLLABORATIONS

COLLABORATIONS

- Bordenave [CNRS], PhD thesis J. Salez
- Draief [Imperial College], PhD thesis H. Amini
- Massoulié [Technicolor], Bordenave, Mairesse [CNRS]
- Aldous [UC Berkeley], Bordenave [CNRS]

THEORETICAL PROBLEMS

- Random assignment problems
- Spectra of large random graphs
- Diffusions in weighted random graphs
- Matching & spanning infinite graphs
- Combinatorial optimization (scaling exponents)

TOOLS

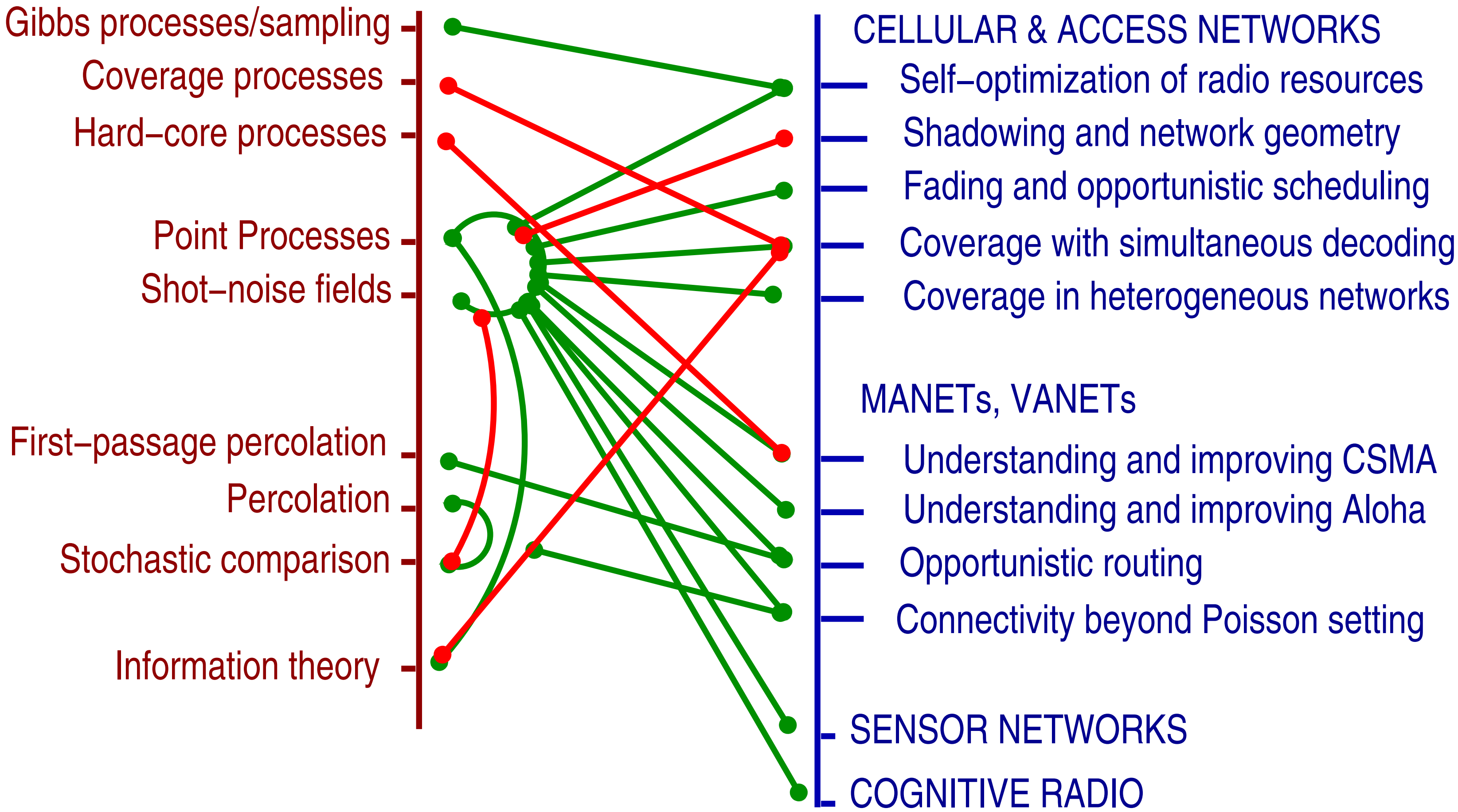
- Local weak convergence (objective method)
- Cavity method
- Belief propagation
- Configuration model

III.2. EUCLIDEAN GEOMETRY AND NETWORKS: WIRELESS STOCHASTIC GEOMETRY

- **Garden**
  - considers **randomly located transmitters & receivers** in space
  - analyzes **averages of I.T. characteristics** over space and channels
  - provides **macroscopic laws** for **coverage, throughput, blocking, connectivity, routing**
  - allows for comparison & optimization of architecture/protocol options in large wireless networks.

III.2. EUCLIDEAN GEOMETRY AND NETWORKS: WIRELESS STOCHASTIC GEOMETRY (*continued*)

MATHs | **APPLICATION DOMAINS**



III.2. A MATH RESULT
STOCHASTIC COMPARISON OF POINT PROCESSES

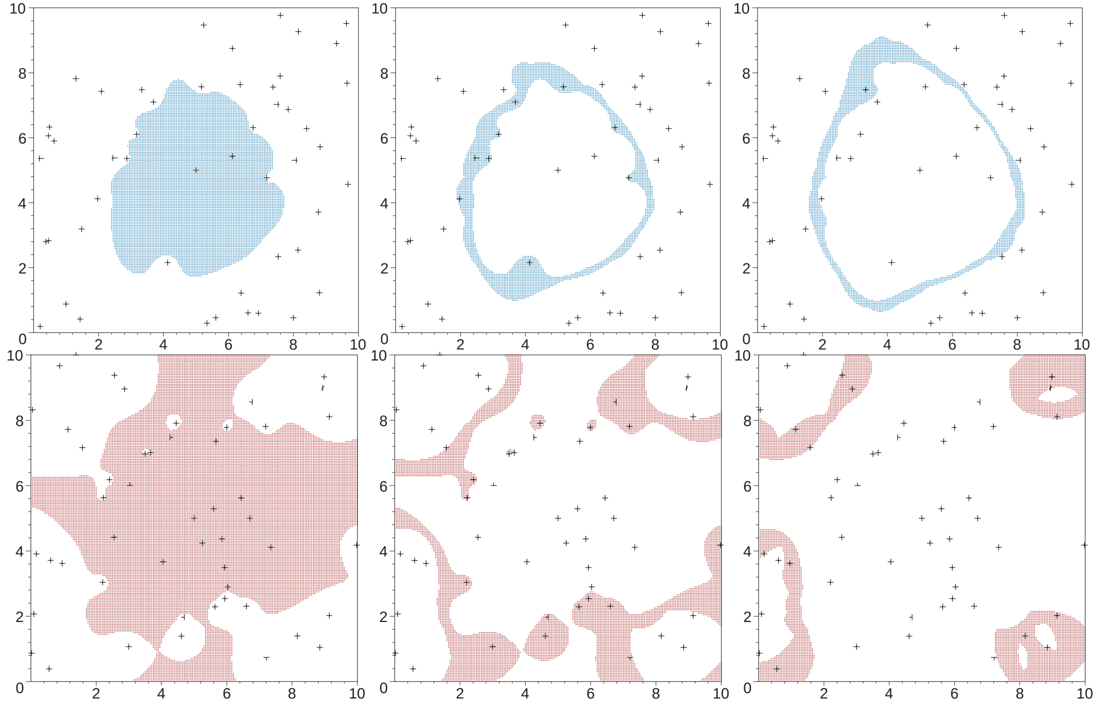
- ϕ **and** ψ **two point processes of the Euclidean space**
- I_ϕ **and** I_ψ **the associated shot noise fields**

$$\phi \leq_{\mathbf{dcx}} \psi \Rightarrow \mathbf{I}_\phi \leq_{\mathbf{dcx}} \mathbf{I}_\psi$$

- **Applications: Node clustering increases moments of interference**
  Further consequences on coverage, throughput, etc.

Thesis of D. Yogeshwaran

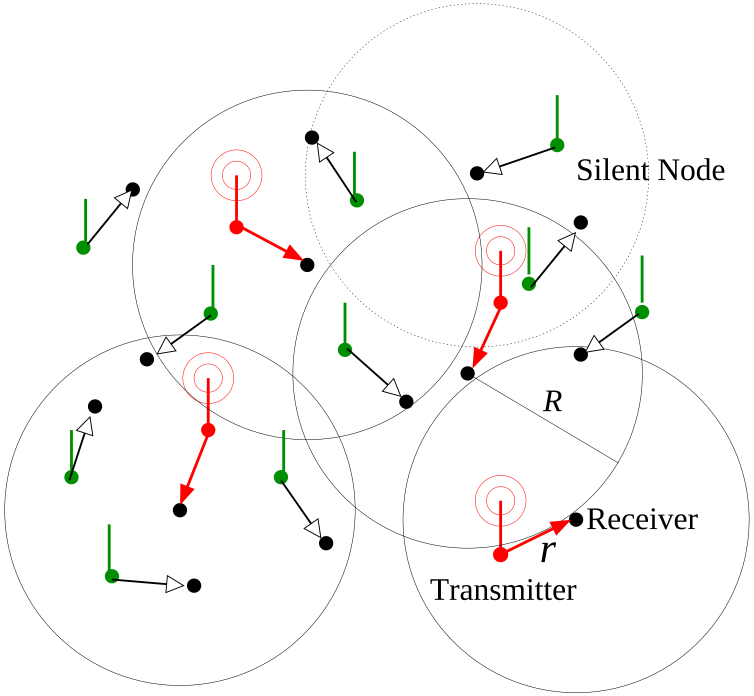
III.2. A GEOMETRIC OBJECT: THE SIM(k) MAC CELL



Left: Ξ^{IAN}**, Center:** $\Xi^{\mathrm{SIM}(1)\setminus\mathrm{IAN}}$**, Right:** $\Xi^{\mathrm{SIM}(2)\setminus\mathrm{SIM}(1)}$

F.B., A. El Gamal and D. Tse, Tr I.T. 2011

FLOWER 4: CSMA IN A POISSON DIPOLE MANET



Hard core exclusion dipoles

- **Carrier Sensing MAC: packings with better SINR guarantees at the receivers compared to Aloha**
- **Hard core exclusion:**
  - **two conflicting transmissions a and b are never simultaneously active**
  - **conflict: e.g. receiver of a within sensing range R of transmitter of b or converse.**

F4: GEOMETRY OF CSMA

- **New Hard Core Exclusion Point Processes**

  1. **Matérn p.p.**
  2. **Random Sequential Packing p.p.**

- **Partially solved mathematical questions on Matérn and RSP**

  – **Construction of the point processes**

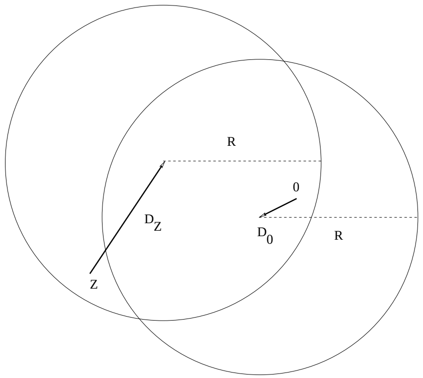
  – **Probability of access to the shared medium**

  – **Laplace transform of the Shot Noise created by the hard core p.p.**

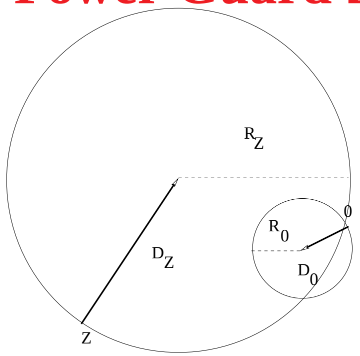
$\Rightarrow$ **SINR of typical dipole & Spatial Throughput**

Thesis of T. V. Nguyen

F4: ADAPTIVE PACKING: FLASHLINQ



WiFi Power Guard Zone

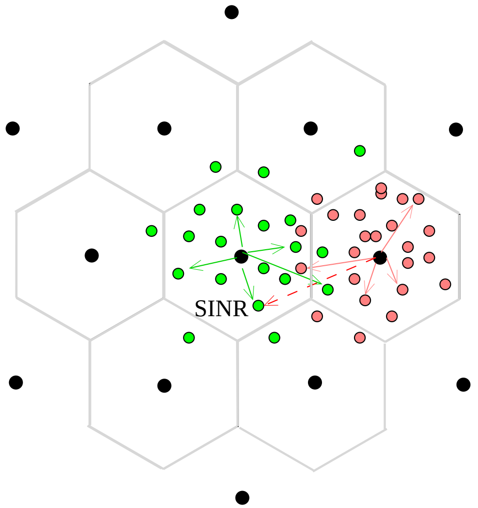


FlashLinq SIR Guard Zone

- **Protocol Comparison**:
  - **Adaptive SIR Guard Zones** compared to Static Power Guard Zones
  - **Adaptive Power Control** compared to Static Power
- **Collaboration with Qualcomm**
  - In the no fading case, taking power as the **inverse of the square root** of the channel gain is optimal in the class of **local information** protocols

F.B., J. Li, T. Richardson, S. Subramanian, X. Wu and S. Shakkottai 12

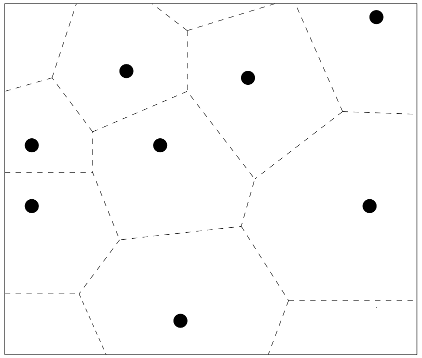
FLOWER 5: CELLULAR NETWORKS ARCHITECTURE AND PERFORMANCE



←Honeycomb

vs

Poisson-Voronoi→



Bivariate point process

QoS of a mobile depends on its SINR wrt serving (best signal) BS.

F5: SHADOWING & CELLULAR GEOMETRY

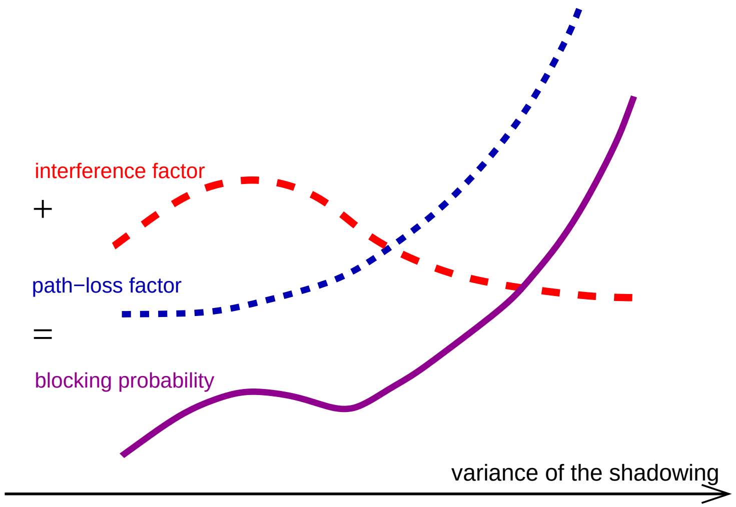
- **Shadowing, signal power loss due to reflection, diffraction, and scattering. Modeled by random field with log-normal marginals with mean 1 and some variance.**
- **Impacts geometry of cellular networks:**
  Serving BS $\equiv$ offering the smallest path-loss $\neq$ the closest one.
- **Shadowing is believed to**
  - **degrade QoS metrics**
  - **harm perfect honeycomb.**

Not always!

F5: LEVERAGING SHADOWING

– **Mean path-loss from serving BS increases in shadow-variance.**

– **Mean interference factor (1/SIR) decreases for large variances!**



Moderate shadow-variance may improve interference-limited QoS!
Decrease of blocking in streaming traffic for indoor scenario.
A fundamental property of heavy tailed shadowing.

B. Błaszczyszyn and M. Karray 2011

F5: SHADOWING MAKES HONEYCOMB LIKE POISSON

- **Observation: Large hexagonal networks with shadowing of sufficiently large variance is perceived at a given location as an "equivalent infinite Poisson network" (without shadowing).**
- **Evidence:**
  - **statistical; by Kolmogorov-Smirnov tests,**
  - **theoretical; proof of convergence of random measures**
- **Exploitation:**
  - **analytically tractable Poisson networks.**
  - **linear regression estimates of path loss parameters.**

B. Błaszczyszyn and M. Karray 2012

III.2. COLLABORATIONS

APPLICATION DOMAINS	INDUSTRIAL	ACADEMIC COLLABORATIONS
CELLULAR & ACCESS NETWORKS		
Self–optimization of radio resources	Alcatel-Lucent	PhD thesis V.–M. Nguyen
Shadowing and network geometry	Orange	Karray [Orange]
Fading and opportunistic scheduling	Orange	
Coverage with simultaneous decoding		Anantharam, Tse [UC Berkeley] El Gamal [Stanford]
Coverage in heterogeneous networks		Andrews, Ganti [UT Austin]
MANETs, VANETs		
Understanding and improving CSMA	Qualcomm	PhD thesis P. Bermolen
Understanding and improving Aloha		Altman [Inria MAESTRO]
Opportunistic routing		Muhlethaler [Inria HIPERCOM]
Connectivity beyond Poisson setting		PhD thesis D. Yogeshwaran
SENSOR NETWORKS		Muhlethaler [Inria HIPERCOM]
COGNITIVE RADIO		

III.2. BOOKS, SPECIAL ISSUES

- **Special Issue of J. Selected Areas in Communications**
  Stochastic Geometry and Random Graphs for the Analysis and Design of Wireless Networks
- **Book: 09 NOW Monograph**
  Stochastic Geometry and Wireless Networks F.B. and B. Blaszczyszyn
  - **Vol. 1, 1114 downloads**
  - **Vol. 2, 795 downloads.**
- **Recent Books directly related to ⓒ Haenggi & Ganti 09, Andrews & Weber 11, Jabbari, Agrawal & Babaei 12**
- **5 best paper awards (including 3 to TREC) to recent WSG papers**

III.2. INDUSTRY IMPACT

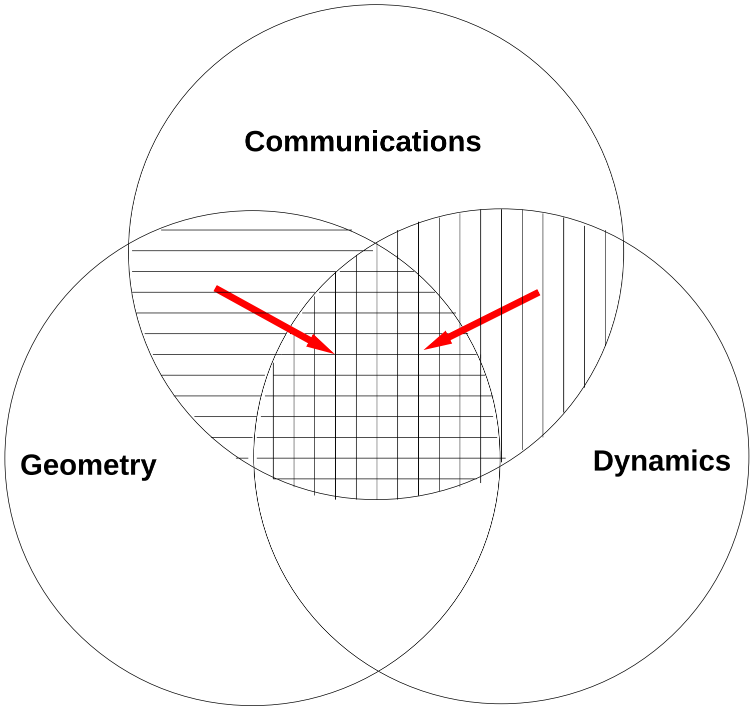
– **Alcatel Lucent**: Gibbsian Self Organization in Cellular Networks; 2 patents, joint papers, one demonstrator, planned prototype for LTE.

– **Technicolor**: Gibbsian Self Organization in Mesh Networks; 1 patent, joint papers, one demonstrator.

– **Orange**: Dimensioning of CDMA Cellular Networks; several joint papers; SERT and UTRANDIM Software.

– **Qualcomm**: Ongoing joint work on FlashLinq; joint papers.

IV. FUTURE



Dynamics

Geometry

$\Downarrow$

Geometric Network Dynamics

Aim: Develop mathematical tools for space–time networking with potential impact ranging from academia to industry

IV. CATEGORIES

1. **Dynamics of geometric networks**
   links changes over time according to an exogeneous dynamics like in preferential attachment
2. **Dynamics on geometric networks**
   links and/or nodes are fixed but harbor local dynamical systems like in queuing on wireless
3. **General Case: of/on: Interplay between**
   - **the dynamics of the network topology**
   - **the local dynamics on the network elements**

IV. EXAMPLES OF TYPE 3

- **Dynamics of/on Matchings, Wireless Networks, etc. but also**
- **Dynamics of/on Peer-to-Peer/CDN**
  - **Neighborhoods define peering patterns**
  - **Nearby peers exchange data at a higher rate and vanish faster**
- **Dynamics of/on Communities in Social Networks**
  - **Cluster of close-by nodes in semantic space capturing interests**
  - **Nodes clustered in the same community interact more**