CONNECT
Networks of the Future

Service-Driven Networks: Resource Sharing and the Future of the Wireless Access

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Rio de Janeiro, Brasil, 16 December 2015

To evolve future wireless networks:

- More spectrum (e.g., mm-wave, licensed + unlicensed)
- More antennas (massive MIMO)
- More technologies

- New spectrum licensing regimes
- Cell densification
- Sharing of infrastructure, backhaul, processing, storage
- Virtualised wireless networks


When you ride ALONE
you ride with Hitler !
Join a
Car-Sharing Club
TODAY !

Vision

Wireless networks of the future will be characterised by heterogeneity

- of spectrum usage regimes
- of ownership models
- of radio access technologies

where resources are shared and orchestrated to create bespoke, virtual networks designed for specific services

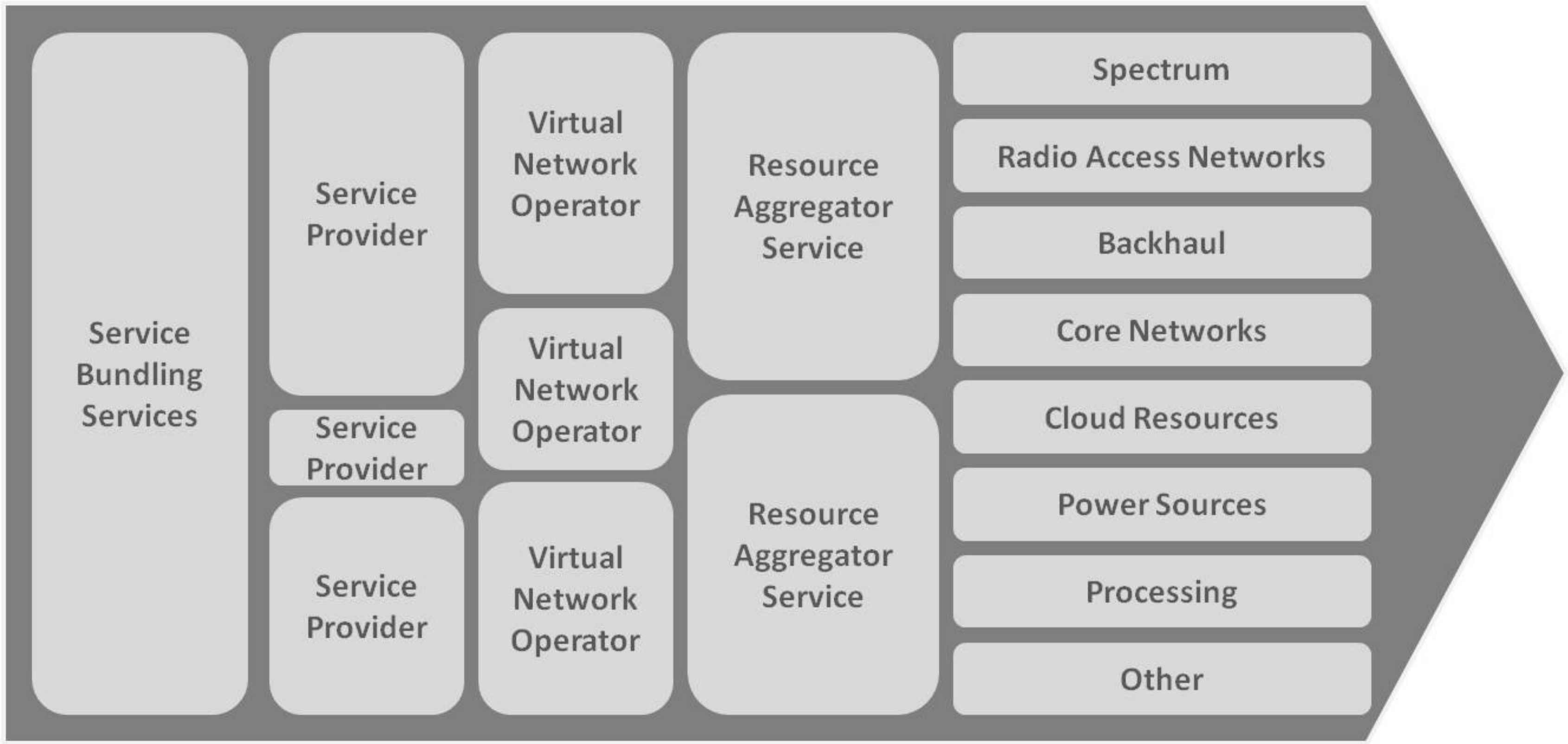
Inter-operator RAN and spectrum sharing is a key step towards that future

- cost efficiencies, tempered by
- competitive advantage considerations
- regulatory constraints

Virtualisation = the illusion of exclusive access to physical resources that are, in fact, shared

A virtual wireless access network feels to the user like a traditional network operated by a single entity but is in fact orchestrated out of a diverse pool of resources with different ownership models

A set of physical resources can host several virtual networks



Future wireless networks will rely on ***sharing*** and ***virtualisation***

… and this requires the ability to slice and trade resources

[Doyle, Forde, Kibiłda, DaSilva, Proc. of IEEE 2014]

Increased efficiency and lower costs through:

1. Incentives for the deployment of localised (small cell, primarily) infrastructure by medium-sized and small operators.

2. The ability to provide service over infra-structure that employs heterogeneous technologies, and has different properties and ownership.

3. Improved service in currently under-served areas.

4. The ability to offer virtual wireless networks with different associated quality of experience, at different price points.

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BUSINESS

ESPN Eyes Subsidizing Wireless-Data Plans

New questions…

1. How to select physical resources to meet the needs of a virtual operator?

2. How to dynamically manage these virtual networks?

3. How to ensure security, and privacy?

4. What economic and public policy models will support this new model?

(…)

Approaches

optimisation

$$\min \sum_{l \in \mathcal{L}} \varphi(l, m^{\star}), \tag{12}$$

subject to:

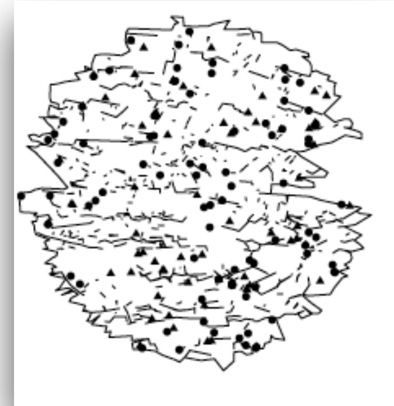
$$\sum_{l \in \mathcal{L}, m \in \mathcal{M}} \sigma_j(l, m, q, \mathrm{GBR}) p(l, q) \geq \sum_{m \in \mathcal{M}} \max\left(d(m, q, \mathrm{GBR}) - \sum_{l \in \mathcal{L}} \sigma_p(l, m, q, \mathrm{GBR}), 0 \right), \forall q \in \mathcal{Q}, \tag{13}$$

$$\sum_{q \in \mathcal{Q}, m \in \mathcal{M}} \sigma_j(l, m, q, \mathrm{GBR}) \leq \varphi(l, m^{\star}) r(l), \forall l \in \mathcal{L}, \tag{14}$$

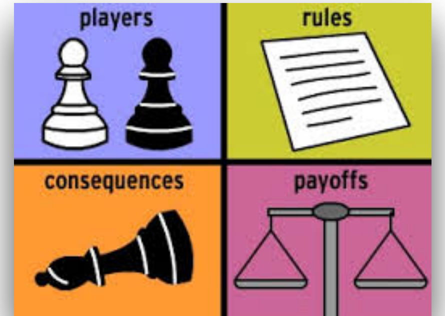
$$\varphi(l, m^{\star}) \in \{0, 1\}, \quad \forall l \in \mathcal{L}, \tag{15}$$

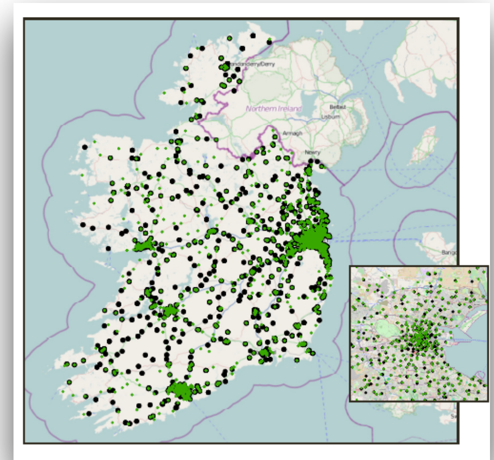
$$\sigma_j(l, m, q, \mathrm{GBR}) \in \mathbb{Z}_{+}, \quad \forall l \in \mathcal{L}, m \in \mathcal{M}. \tag{16}$$

stochastic geometry



game theory

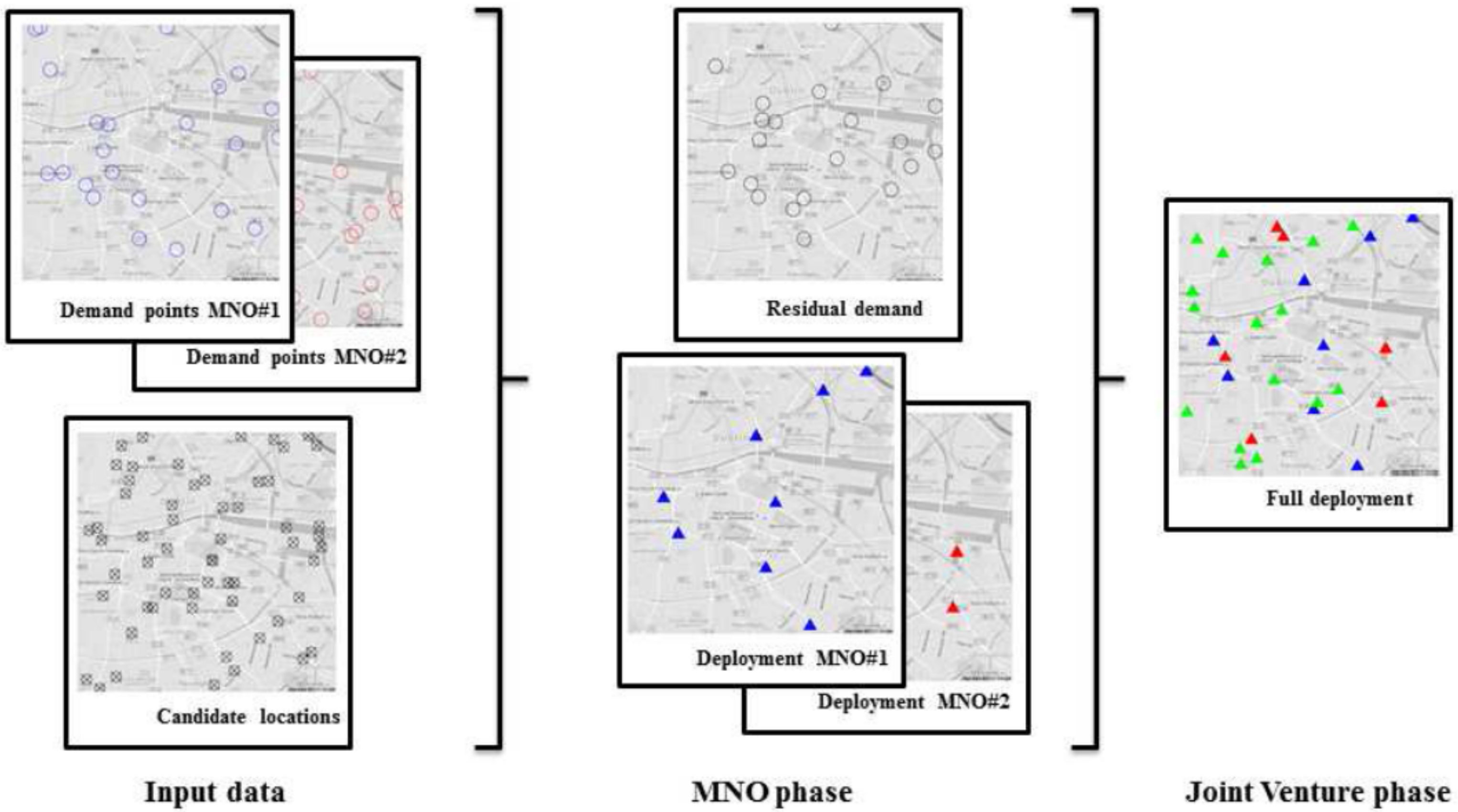




real data

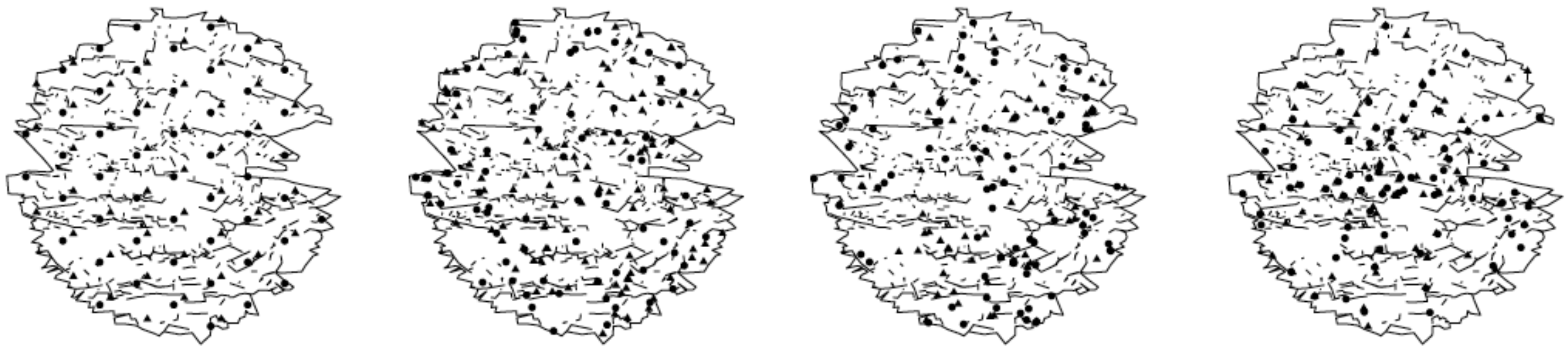
Optimization

To assess gains from resource sharing under diverse sets of technical, market, and regulatory constraints



Stochastic Geometry

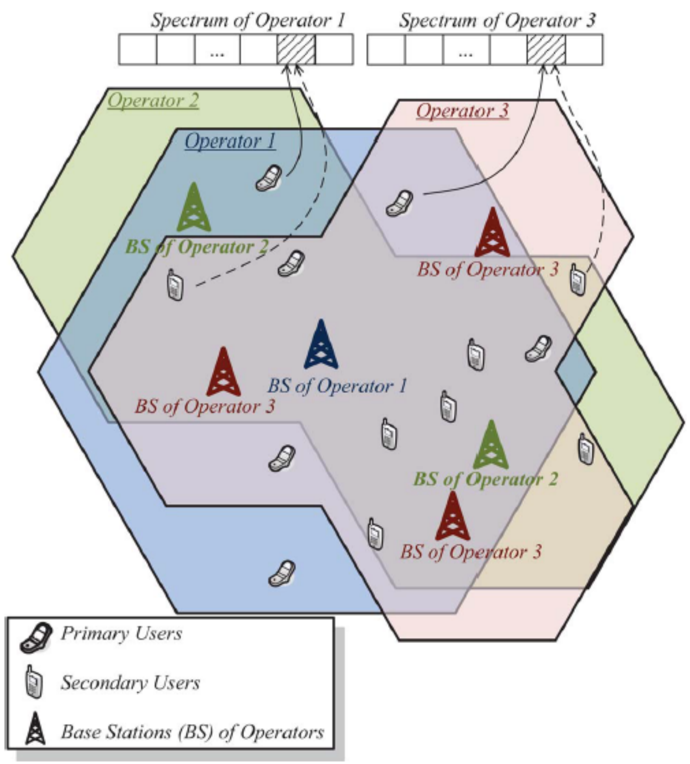
To find appropriate stochastic models for combined network deployments by multiple operators, and to assess the resulting performance of shared networks

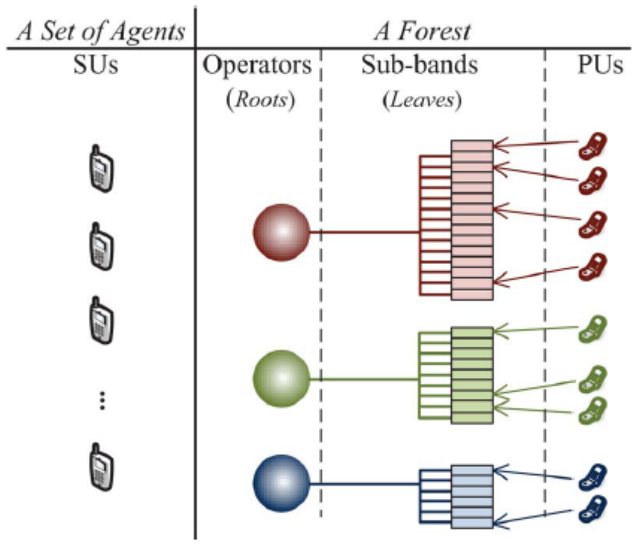


(a) Hexagonal (b) Poisson (c) log-Gauss Cox (d) Real

Game Theory

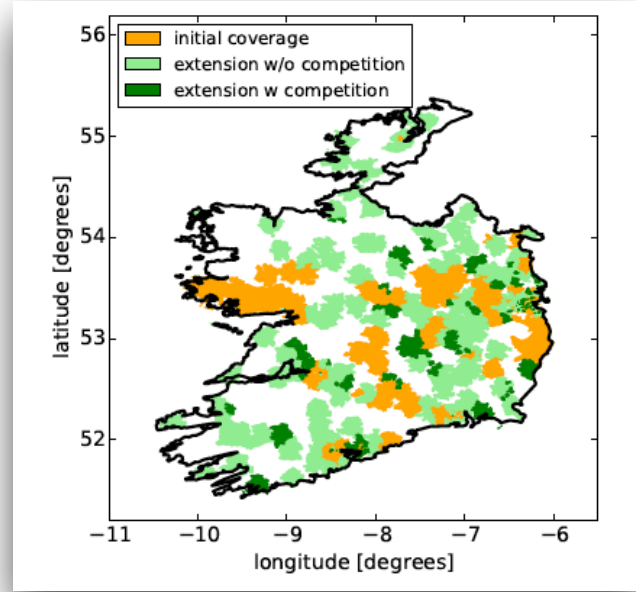
To assess the effect of possibly conflicting objectives among independent decision makers and to design mechanisms that lead to socially desirable outcomes



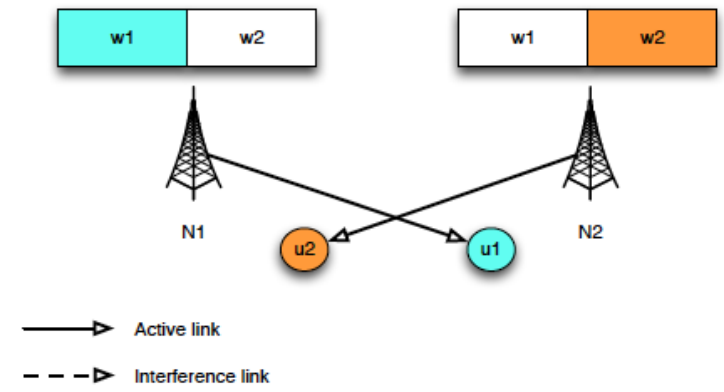


Our starting point…

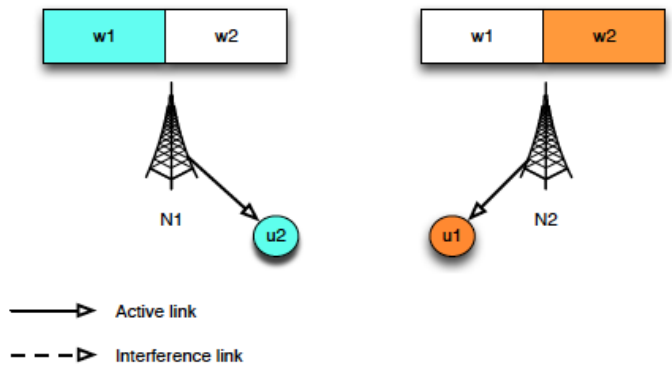
Sharing decisions among network operators



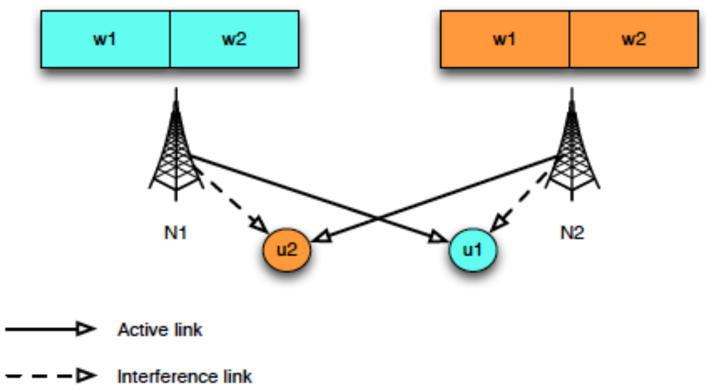
Illustrative problem: can infrastructure sharing be traded for spectrum sharing?



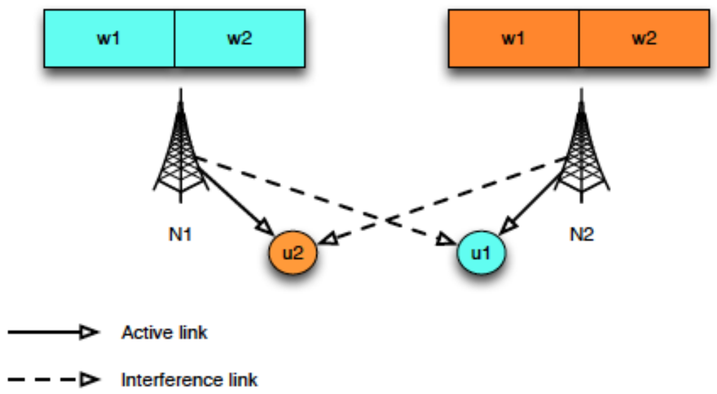
No sharing



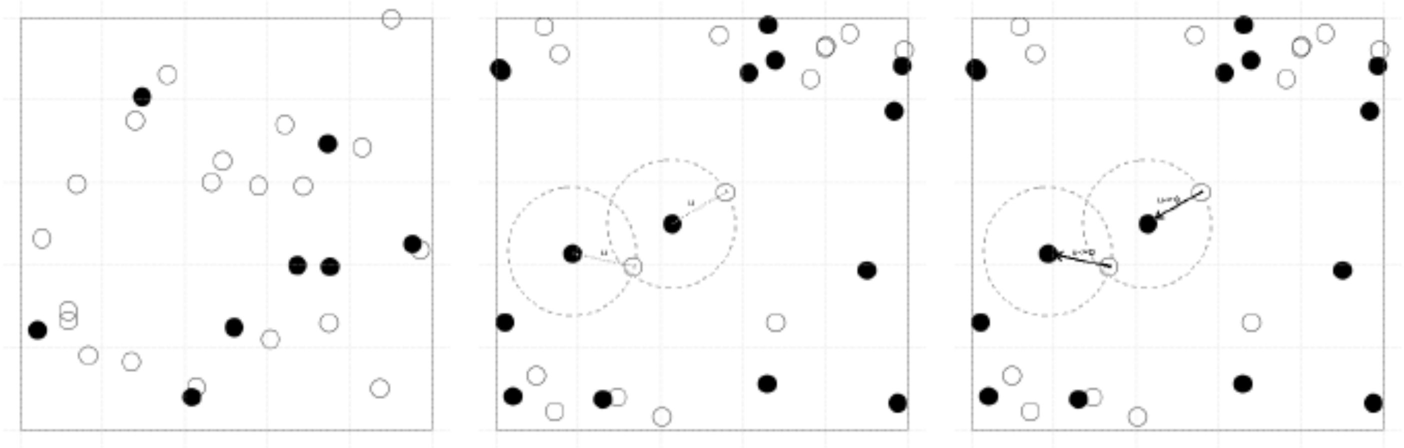
Infrastructure only



Spectrum only



Infrastructure + Spectrum



(a) PPP (b) GPP ($u > 0$) (c) GPP ($u \leftarrow 0$)

[Kibiłda, Di Francesco, Malandrino, DaSilva, IEEE DySPAN 2015]

Some results…

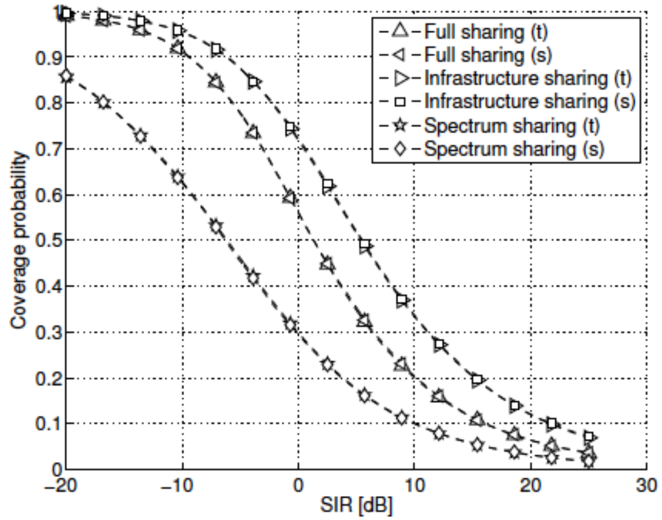
Coverage probability

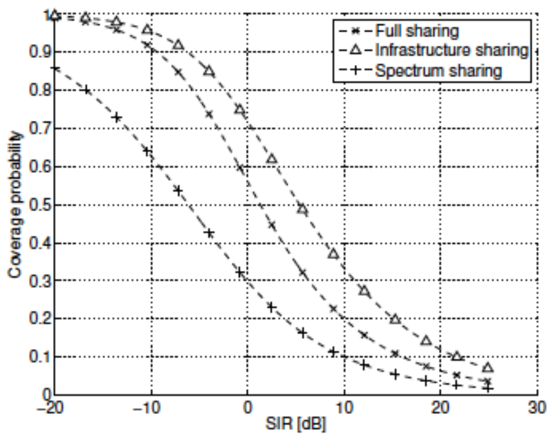
Full sharing	p_c^{ns}
Infrastructure sharing	$\sum_{i\in\mathcal{N}} \frac{\lambda_i}{\lambda+\lambda_i\theta^{\frac{1}{2}}(\frac{\pi}{2}-\arctan(\theta^{-\frac{1}{2}}))}$
Spectrum sharing	$\frac{\lambda_i}{\lambda_i+\lambda_i\theta^{\frac{1}{2}}(\frac{\pi}{2}-\arctan(\theta^{-\frac{1}{2}}))+\frac{\pi}{2}\theta^{\frac{1}{2}}\sum_{j\in\mathcal{N}\setminus\{i\}}\lambda_j}$

Average user rate

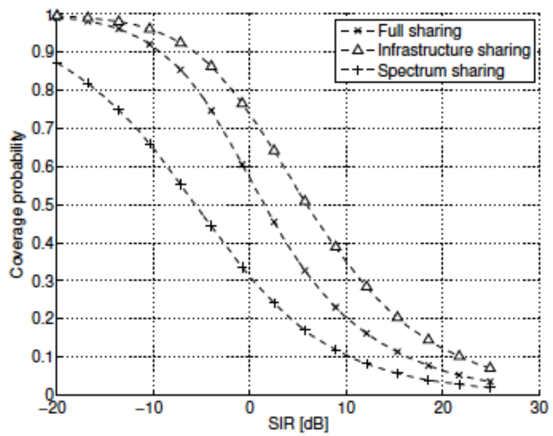
Full sharing	$\frac{\sum_{i\in\mathcal{N}} w_i}{w_i}\mathcal{T}^{ns}$
Infrastructure sharing	$w_i \int_{0+}^{\infty} p_c^{is}(\gamma)\exp(-\log(\gamma-1))d\gamma$
Spectrum sharing	$\left(\sum_{j\in\mathcal{N}} w_j\right)\int_{0+}^{\infty} p_c^{ss}(\gamma)\exp(-\log(\gamma-1))d\gamma$

- Validation of closed-form expressions for coverage probability (hPPP)

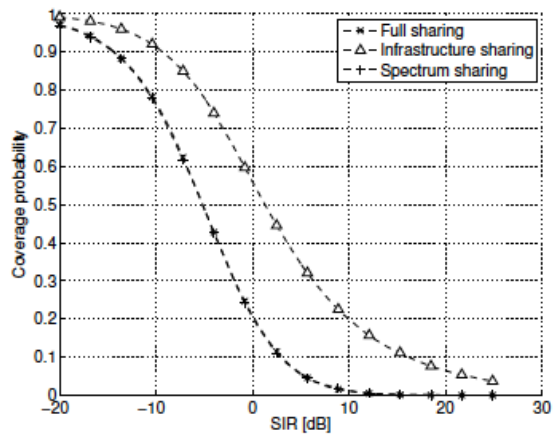




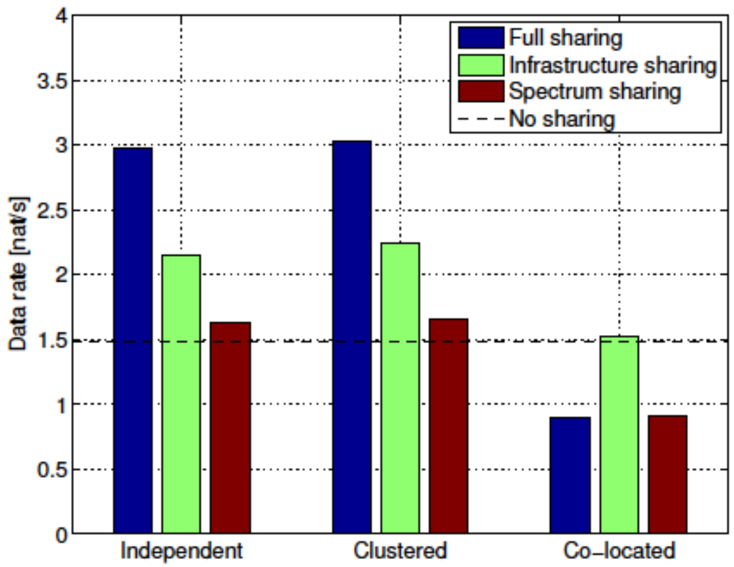
Independently deployed infrastructure



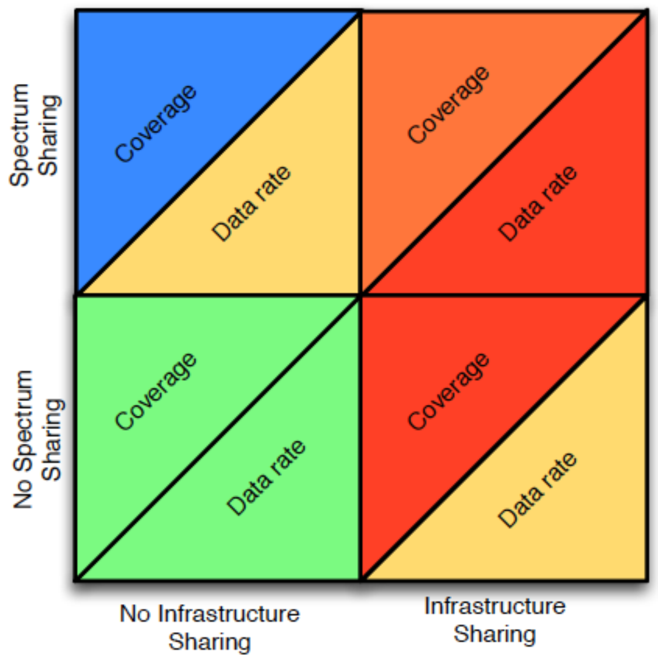
Clustered infrastructure



Co-located infrastructure



Effects on data rate



- Infrastructure and spectrum cannot be simply substituted for each other, as they bring a tradeoff in coverage and capacity

- The combination of infrastructure and spectrum sharing does not bring linearly scaling gains

- The spatial distribution of the networks has a significant impact on the gains brought about by sharing

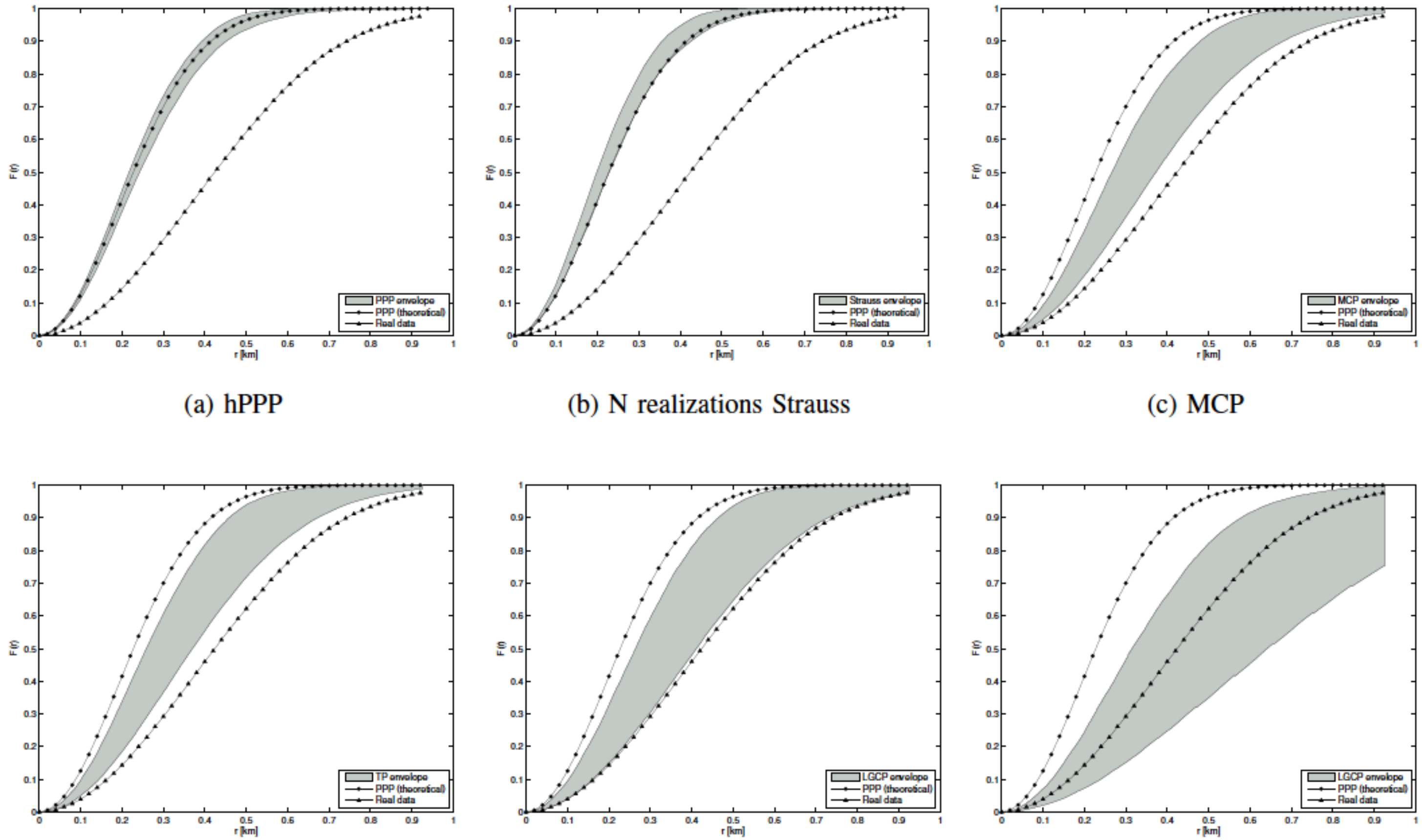
- The respective densities of the networks of the two operators influences how each perceives the sharing gains

- Results of spectrum sharing are overly pessimistic as they consider no spectrum management or frequency planning

Clustered point processes to model multi-operator deployments

- Premise: multi-operator RAN deployments exhibit significantly more clustering than single-operator
- Investigate goodness of fit of log-Gaussian Cox process (LGCP), Matern cluster process (MCP) and Thomas process (TP)
- Deployment data from Ireland, Poland, and the UK

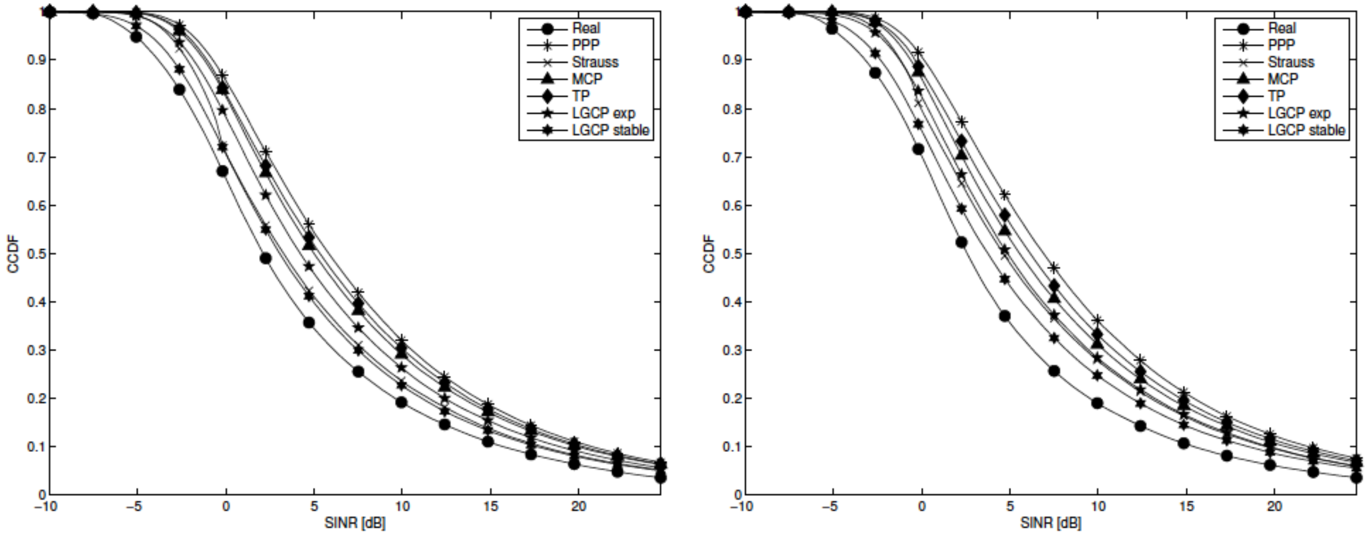
Hexagonal PPP LGCP Dublin (real data)



(a) hPPP (b) N realizations Strauss (c) MCP

(d) TP (e) LGCP exponential (f) LGCP stable

- Empty space function (F function), fitted with a second-order statistic (pair-correlation function)
- Fit shown for UMTS deployments in Dublin (Three, Vodafone, Meteor)
- Envelope of 99 realisations of the fitted point process model shown in grey
- Similar results for other urban areas investigated



(a) GSM (b) UMTS

- Coverage probability: again LGCP provides the closest match to real data
- Combined multi-operator deployments seem to cluster at shorter distances (high demand areas) and repulse at longer
- LGCP and cluster point processes provide a reasonable fit to such multi-operator deployments
- Results are robust to various countries tested for in Europe

[Kibilda, Galkin, DaSilva, TMC 2016]

- Sharing (of infrastructure, spectrum, processing, …) will be increasingly important as wireless networks evolve
- Optimisation, game theory, stochastic geometry are complementary approaches to better understand the effects and limitations of sharing
- Significant cost savings are in play, even when competitive concerns and regulatory constraints are present
- Recent research on SDN, NFV, etc. will be helpful in designing the mechanisms for the virtualisation of wireless networks
- Next: mathematical extensions of infrastructure and spectrum sharing analysis to account for clustering, management of shared resources, etc.

Acknowledgements

Danny Finn, Nick Kaminski, Boris Galkin, Hamed Ahmadi, Paolo Di Francesco, Jacek Kibiłda, Francisco Paisana, João Santos, Zaheer Khan, Johann Marquez-Barja

Science Foundation Ireland

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HORIZON 2020