Sharing and Virtualization in Future Wireless Networks

Luiz DaSilva

Stokes Professor in Telecommunications

Professor

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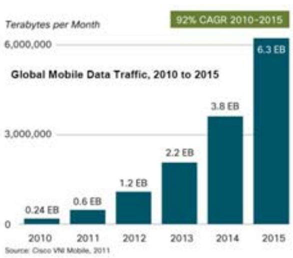

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Sharing, Sharing, Sharing

- Infrastructure sharing among operators
- Spectrum sharing
- Sharing of crowdsourced infrastructure

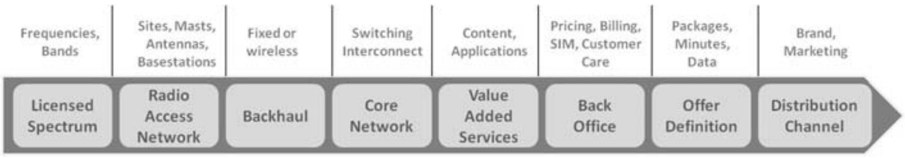
the STORY of…

✓ The ability to instantiate wireless networks dynamically, in response to dynamic changes in demand and customized to specific service requirements

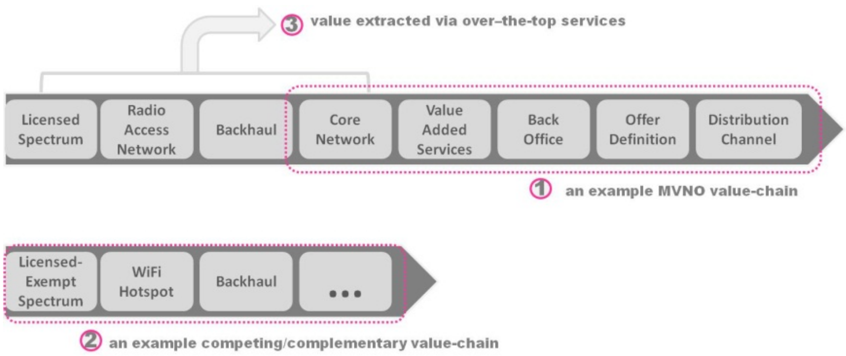
OR

✓ Networks without borders

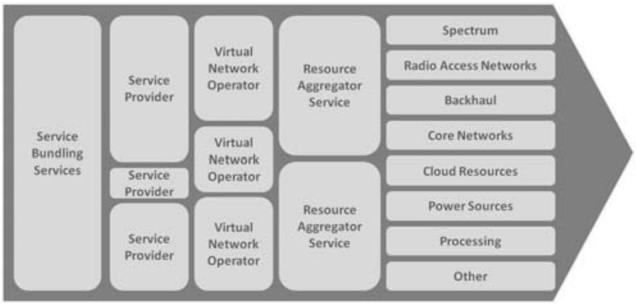
Mobile Network Operator (MNO) value chain



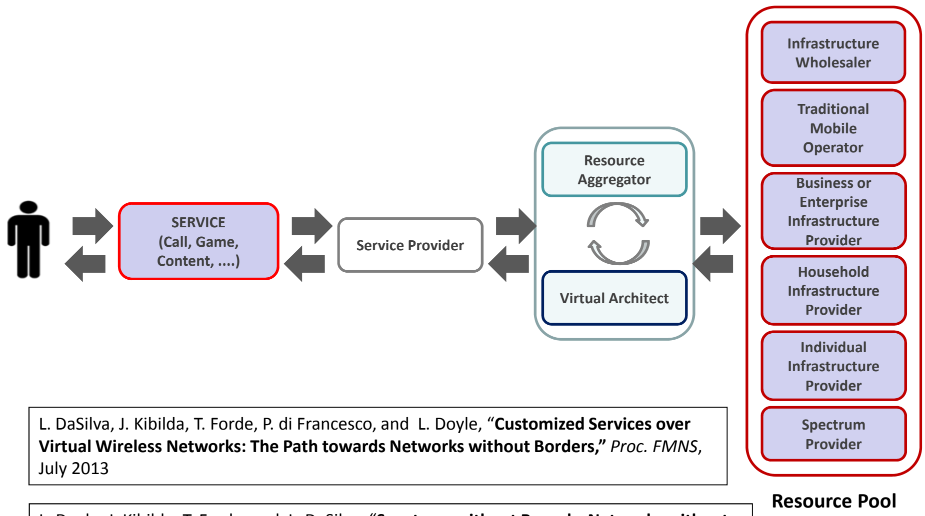
Some issues with the MNO value chain



A future based on sharing and virtualization



Customized virtual networks



L. DaSilva, J. Kibilda, T. Forde, P. di Francesco, and L. Doyle, "**Customized Services over Virtual Wireless Networks: The Path towards Networks without Borders,**" *Proc. FMNS*, July 2013

L. Doyle, J. Kibilda, T. Forde, and L. DaSilva, "**Spectrum without Bounds, Networks without Borders**," *Proceedings of the IEEE*, March 2014.

Increased efficiency and lower costs through…

❶ Incentives for the deployment of localized (small cell, primarily) infrastructure by medium-sized and small operators

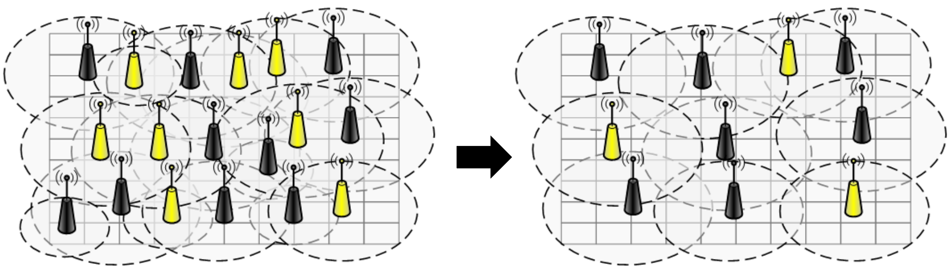
❷ The ability to provide service over infra-structure that employs heterogeneous technologies, and has different properties and ownership

❸ Improved service in currently under-served areas

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

Sharing and macrocells: coverage and capacity

Network shaping (or NIaaS): Architect a network that meets the service requirements at a minimum resource cost



Coverage optimization

$$\min_{\{x_j, z_i\}} \sum_{j \in S} c_j x_j$$

s.t.:

$$\sum_{j \in S} a_{ij} x_j \geq z_i, \forall i \in P$$

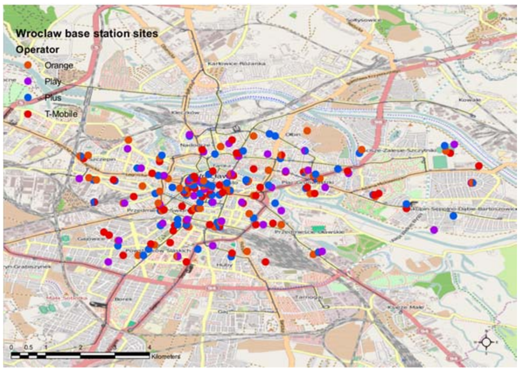
$$\sum_{i \in P} (1 - z_i) \log(\Pr(\xi_i = 0)) \geq \log(p)$$

$$x_j \in \{0,1\}, \forall j \in S$$

$$z_i \in \{0,1\}, \forall i \in P$$

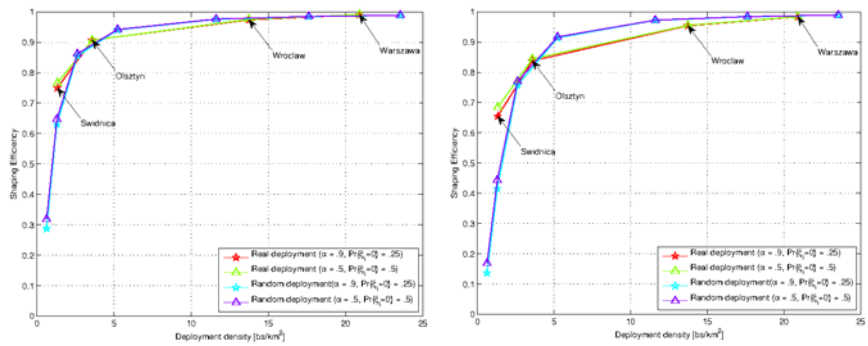
Where $a_{ij} = \mathbb{I}(\frac{r_{ij}}{r_i^*} \geq 1)$, p denotes pre-specified reliability level and ξ_i denotes service request coming from pixel i

Case study: Poland



Area	BS	GSM900 BS	GSM1800 BS	UMTS BS	Intra-operator Co-located [%]	Inter-operator co-located [%]
Warszawa	514	423	174	337	54.9	4.5
Wrocław	273	207	122	229	66.3	8.1
Olsztyn	74	56	37	68	79.7	5.4
Świdnica	29	27	13	20	65.5	6.9

Coverage sharing – efficiency results

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Efficiency gain through infrastructure sharing for uniform deployment and Polish
case study; a) homogeneous power allocation, b) heterogeneous power allocation
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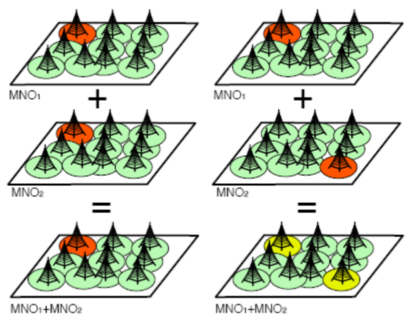
J. Kibiłda and L. DaSilva, **"Efficient Coverage through Inter-operator Infrastructure Sharing in Mobile Networks,"** *in Proc. of Wireless Days*, November 2013.

Traffic dynamics

- Dataset from two Irish operators
  - Data sessions (2G/3G)
  - Voice call records (2G/3G)
  - 10,000 2G (GSM/GPRS) and 12,000 3G (W-CDMA/HSPA) transmitters

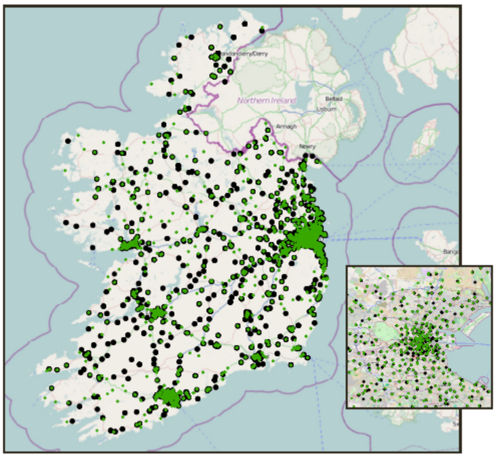


- Better understanding of traffic dynamics in cellular networks
  - Temporal characteristics
  - Spatial characteristics
  - Spatio-Temporal characteristics
  - Correlation in demand
- The latter is the critical factor in determining the desirability of sharing

The data set

- Call detail records
- For each transmitter: position, azimuth, sectorization, coverage area
- For voice call and data session: transmitter where it started/ended, duration, amount of data

Technology	MNO_1	MNO_2	Total
3G (W-CDMA/HSPA)	5656	6679	12335
2G (GSM/GPRS)	5423	4040	9463



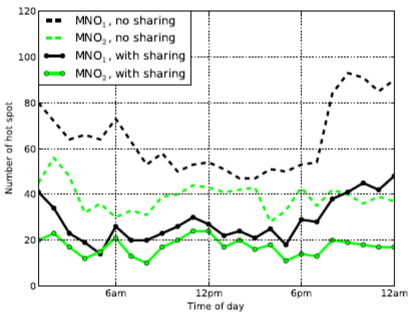
- Black: MNO_1
- Green: MNO_2

(Inset shows Dublin)

Geographical correlation in demand

- Assessed the presence of 'hot spots' – high load sectors surrounded by low load ones
- Also assessed the temporal and geographical correlation on demand

		Operator	Ireland	Urban	Rural
Deployment density [sectors/km^2]		MNO_1	0.080	4.488	0.040
		MNO_2	0.095	5.615	0.042
Space correlation [Moran's Index]	we	MNO_1	0.10	0.08	0.11
		MNO_2	0.13	0.11	0.25
	wd	MNO_1	0.07	0.08	0.10
		MNO_2	0.04	0.04	0.11
hot spot reduction	we	MNO_1	-55%	-38%	-93%
		MNO_2	-55%	-35%	-50%
	wd	MNO_1	-64%	-46%	-96%
		MNO_2	-54%	-44%	-93%



3G data, all Ireland, weekdays

P. Di Francesco, F. Malandrino, L. DaSilva, "**Network Sharing in Cellular Networks: a Trace-Driven Analysis**," *ACM SIGCOMM Workshops*, 2014

Current areas of investigation…

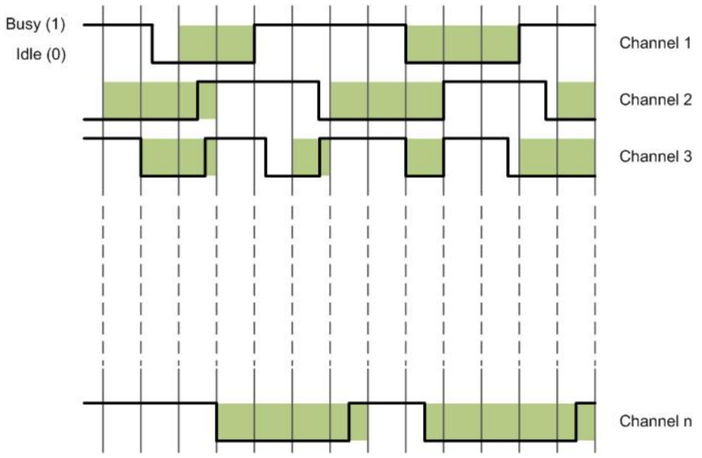
- Quantifying the expected efficiency gain from increased resource sharing and its relationship to correlation in demand experienced by infrastructure providers
- Stochastic geometry models of infrastructure deployment and study of the impact of different infrastructure density and distribution on the potential efficiency gains from sharing
- Game theoretic models of incentives and preferences from the different players in this architecture, capturing the geographic nature of wireless access resources

the STORY of…

✓ The selection of bundles of channels for opportunistic use, à la the three-tier system proposed by the PCAST report

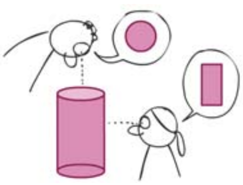
OR

✓ What does Lempel-Ziv complexity have to do with learning about primary activity in shared spectrum?



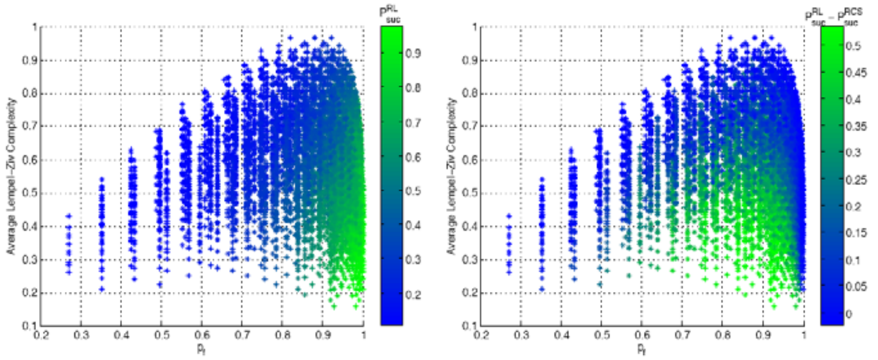
- ✓ Suppose a primary wants to divide its spectrum into bundles of channels for which it grants opportunistic usage rights
- ✓ How to pick equivalent (*fungible*) bundles?

- ✓ The obvious answer: use *duty cycle* to characterize the desirability of a channel



- ✓ The ability to take advantage of dynamic variations in channel usage is highly dependent on the amount of structure in this usage → *Lempel Ziv complexity*

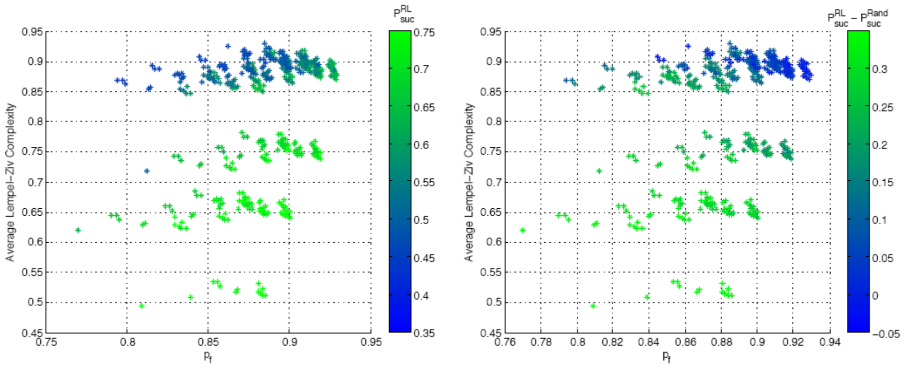
Reinforcement learning and LZ complexity



- ✓ Performance of Q-learning, as a function of LZ-complexity and the probability of at least one free channel existing
- ✓ S = 3 channels, 2-state MC model of channel activity

I. Macaluso, D. Finn, B. Ozgul, L. DaSilva, "**Complexity of Spectrum Activity and Benefits of Learning for Dynamic Channel Selection**," *IEEE JSAC*, 2013

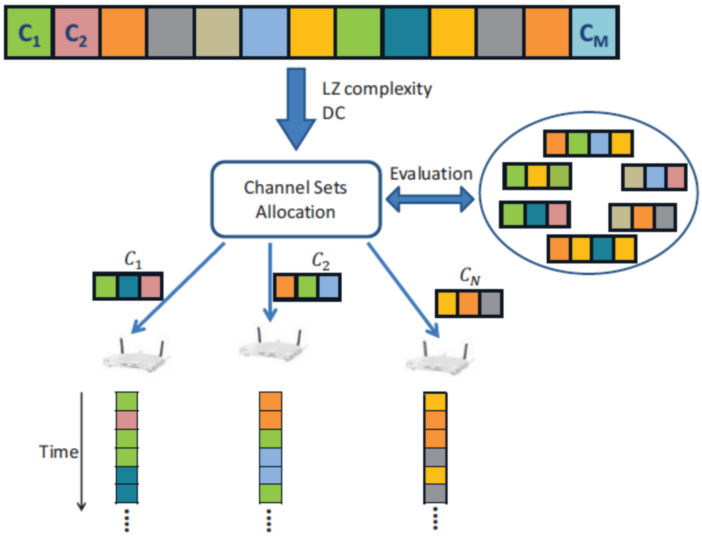
Reinforcement learning and LZ complexity



- ✓ Performance of Q-learning, as a function of LZ-complexity and the probability of at least one free channel existing
- ✓ S = 3 channels, real measurements in ISM band, outdoors

I. Macaluso, D. Finn, B. Ozgul, L. DaSilva, "**Complexity of Spectrum Activity and Benefits of Learning for Dynamic Channel Selection**," *IEEE JSAC*, 2013

Selecting sets of channels for LSA



Problem formulation

- ✓ We formulate the selection of the channel sets as:

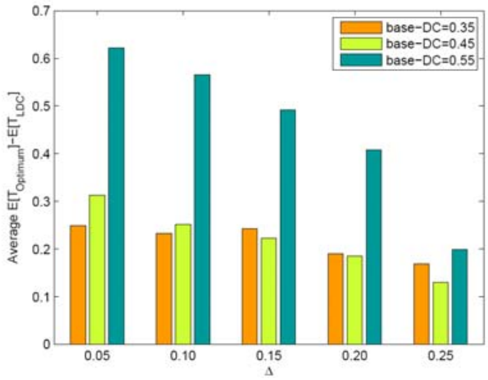
$$\max_{\mathcal{C}_i} \min\{u(\mathcal{C}_i)\}$$

$$s.t.$$

$$\mathcal{C}_i \cap \mathcal{C}_j = \emptyset \qquad \forall i, j \in N, i \neq j$$

$$\mathcal{C}_i \in \mathcal{P}_\alpha(\mathcal{S}) \qquad \forall i \in N$$

- ✓ $\boldsymbol{S} = \{1, \dots, S\}$ is the set of channels and the set of wireless systems is denoted by $\boldsymbol{N} = \{1, \dots, N\}$
- ✓ $\boldsymbol{P}_\alpha(\boldsymbol{S})$ is the set of subsets C of S with cardinality |C|=α

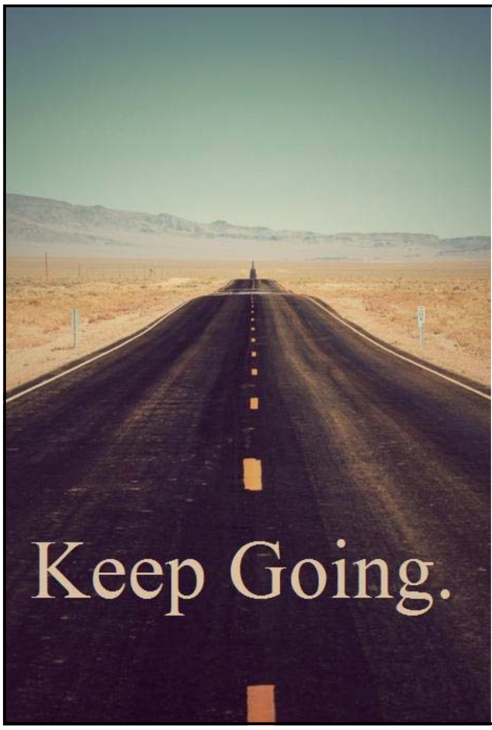


- ✓ 3 wireless networks, 20 channels (10 with high LZ and base DC as indicated, and 10 with low LZ and DC = base-DC + Δ)
- ✓ Improvement over simply selecting channels with lowest DC

I. Macaluso, H. Ahmadi, L. DaSilva, "**Fungible Orthogonal Channel Sets for Multi-user Exploitation of Spectrum**," *submitted*, 2014

Current areas of investigation…

- Distributed resource management mechanisms under imperfect information (game theoretic models)
- Fungibility in virtual networks built on multi-provider infrastructure and heterogeneous access technologies
- Spectrum sharing solutions for small cell deployments coexisting with radar bands



- ✓ **Sharing**: why stop with spectrum?
  - ✓ Base stations, backhaul, storage, processing, back office, …
  - ✓ Crowdsourcing
- ✓ **Virtualization**: why stop with SDNs?
  - ✓ Virtualizing the wireless access