Market Structure, Investment, Network Sharing in Mobile Telecommunications

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QUESTIONS

1. What is the optimal market structure in mobile telecom?
2. What is the welfare impact of network sharing?
3. What is the impact of shared infrastructure in terms of connectivity and inclusion?

Optimal Market Structure

- Based on

"*Market Structure, Investment and Technical Efficiencies in Mobile Telecommunications*"

Co-authored with J. Elliott, G. Houngbonon and P. Scott

Already available on website of *Journal of Political Economy*

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"Market Structure, Investment and Technical Efficiencies in Mobile Telecommunications"

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Motivations

- Competition policy: Impact of market power and scale efficiencies in merger analysis
- Regulation policy: Impact of spectrum allocation on market structure
  - Trade-off quality – price
  - Trade-off between more concentration vs more competition

A structural econometric analysis

1. French mobile telecommunications market
2. Data
3. Competition model in prices, quality and infrastructure
   - Key component: Engineering relationships
4. Simulations

French Telecommunications Market

1. 4 MNOs
2. Some sharing infrastructure with MVNOs

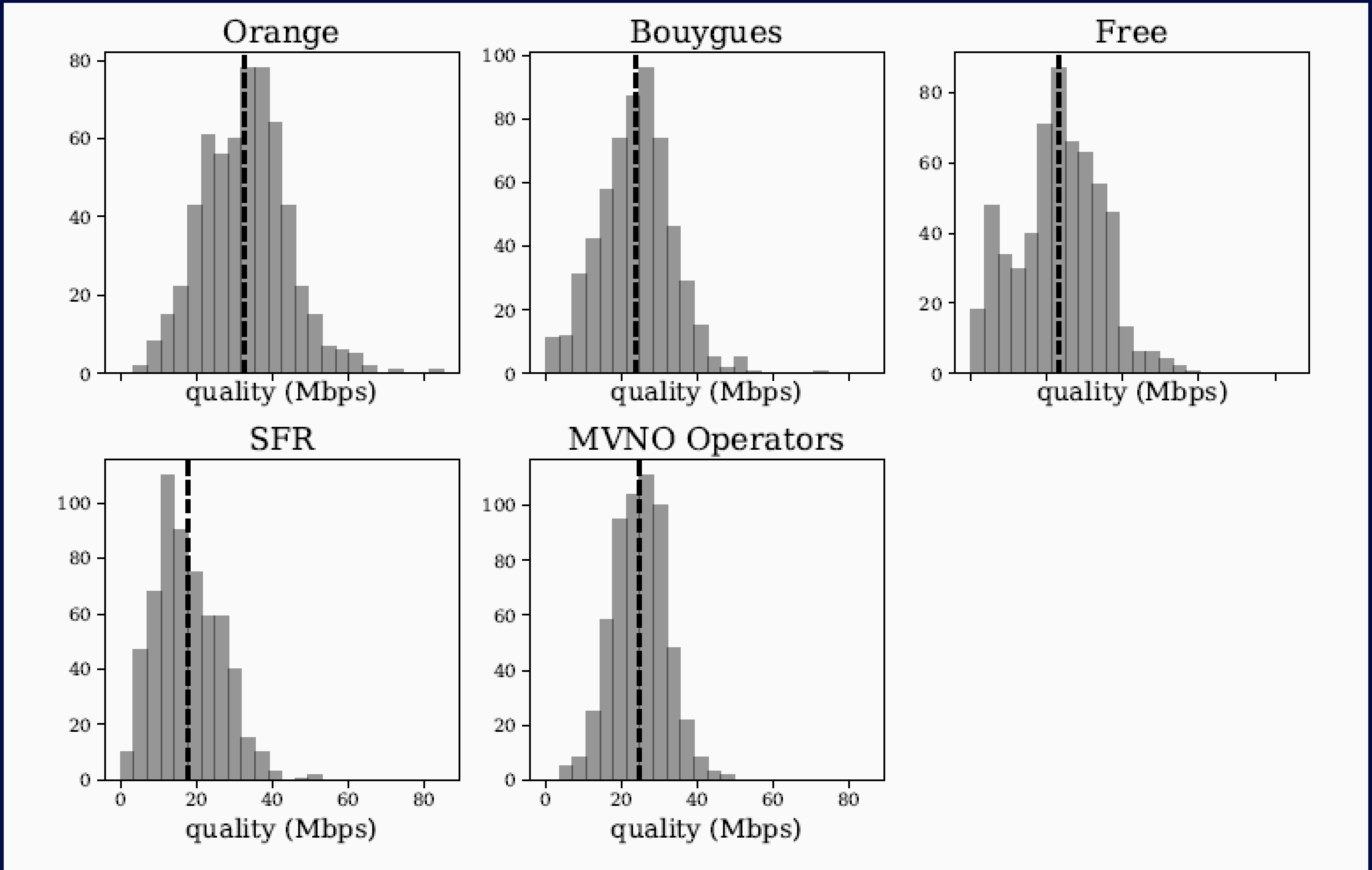
Orange	Bouygues	Free	SFR	MVNO
31.76%	14.12%	14.12%	24.71%	15.29%

3. In 2015
   - 90% of population over 12 has a mobile
   - 4G largely deployed

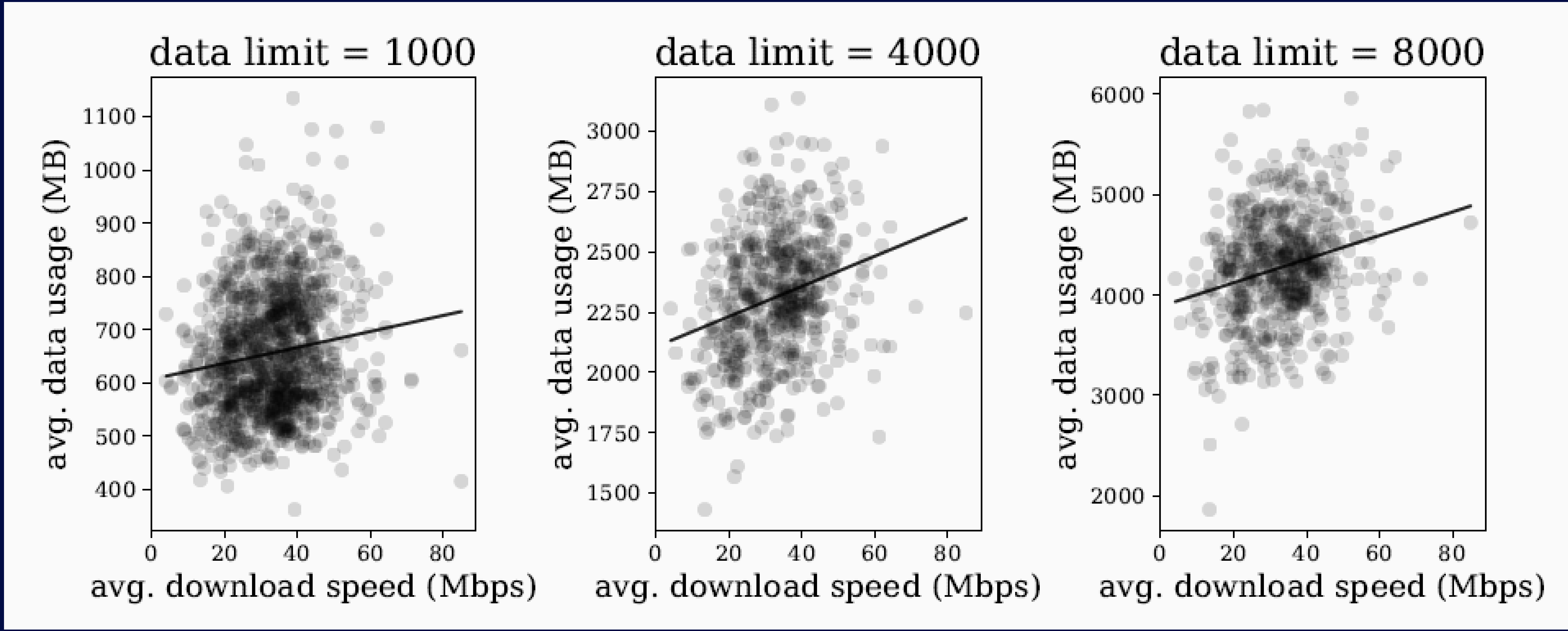
Data

- Detailed municipality-product-level data for all customers from Orange
- Aggregate (national) market shares for other operators
- Full menu of contracts for each operator obtained from catalogs
- Firm-municipality download speeds from Ookla
- Demographic information from INSEE
- Detailed infrastructure data (publicly available) from ANFR

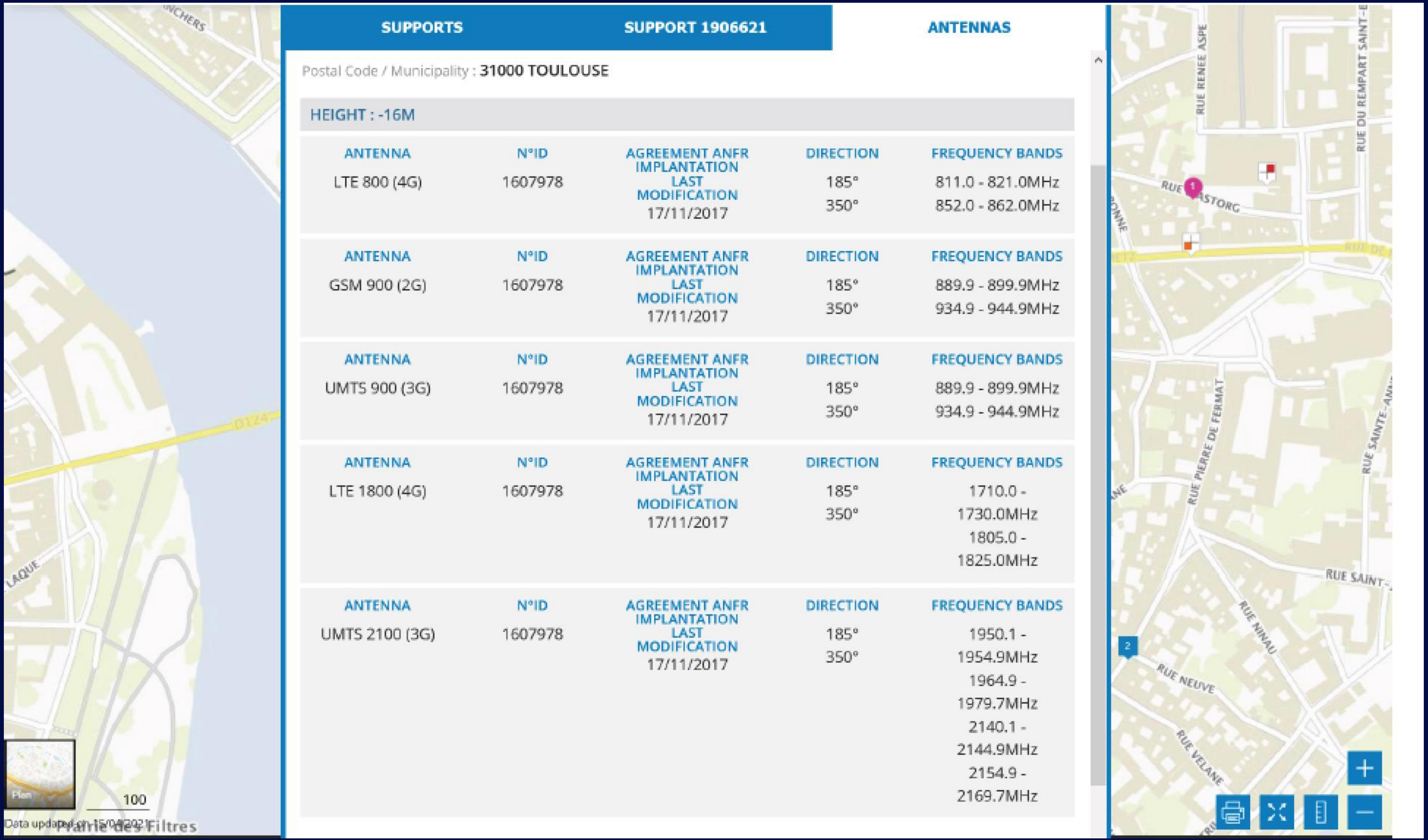
Download speed



Demand and quality



Infrastructure data



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HEIGHT : -16M

ANTENNA	N°ID	AGREEMENT ANFR IMPLANTATION LAST MODIFICATION	DIRECTION	FREQUENCY BANDS
LTE 800 (4G)	1607978	17/11/2017	185° 350°	811.0 - 821.0MHz 852.0 - 862.0MHz
GSM 900 (2G)	1607978	17/11/2017	185° 350°	889.9 - 899.9MHz 934.9 - 944.9MHz
UMTS 900 (3G)	1607978	17/11/2017	185° 350°	889.9 - 899.9MHz 934.9 - 944.9MHz
LTE 1800 (4G)	1607978	17/11/2017	185° 350°	1710.0 - 1730.0MHz 1805.0 - 1825.0MHz
UMTS 2100 (3G)	1607978	17/11/2017	185° 350°	1950.1 - 1954.9MHz 1964.9 - 1979.7MHz 2140.1 - 2144.9MHz 2154.9 - 2169.7MHz

Competition model

- Demand
  - Consumers choose phone plan to subscribe to and how much data to consume given prices and download speeds
- Data Transmission
  - Engineering relationships determine download speeds given infrastructure investment and data consumption
- Firm Competition
  - Firms choose prices and infrastructure investments (# of stations) given bandwith allocation and download speeds

Demand model

- Discrete-continuous choices
  - Choice of how much data consumption, based on download speeds, data limit, consumer type, and an idiosyncratic monthly shock
  - Choice of firm and contract anticipating optimal data consumption
- Utility function has terms for price, value of data consumption, dummy for unlimited voice allowance
- Mixed nested logit
  - Coefficients on price, value of data are function of income
  - Outside option has its own nest

Demand model

$$v\left(j,x,m;\theta_i,\zeta_i,\varepsilon_i\right) \equiv u\left(j,x,Q_{m,f(j)};\theta_i,\zeta_i\right) - \theta_{pi}p_j + \xi_{jm} + \varepsilon_{ij}$$

- ζ_i random variable realized after choice of j but before choice of x

$$\zeta_i \sim Exponential\left(\theta_{di}\right)$$

- Choice of how much data to consume:

$$x_m^*\left(j;\theta_i,\zeta_i\right) = \arg\max_{x}\left\{u\left(j,x,Q_{m,f(j)};\theta_i,\zeta_i\right)\right\}$$

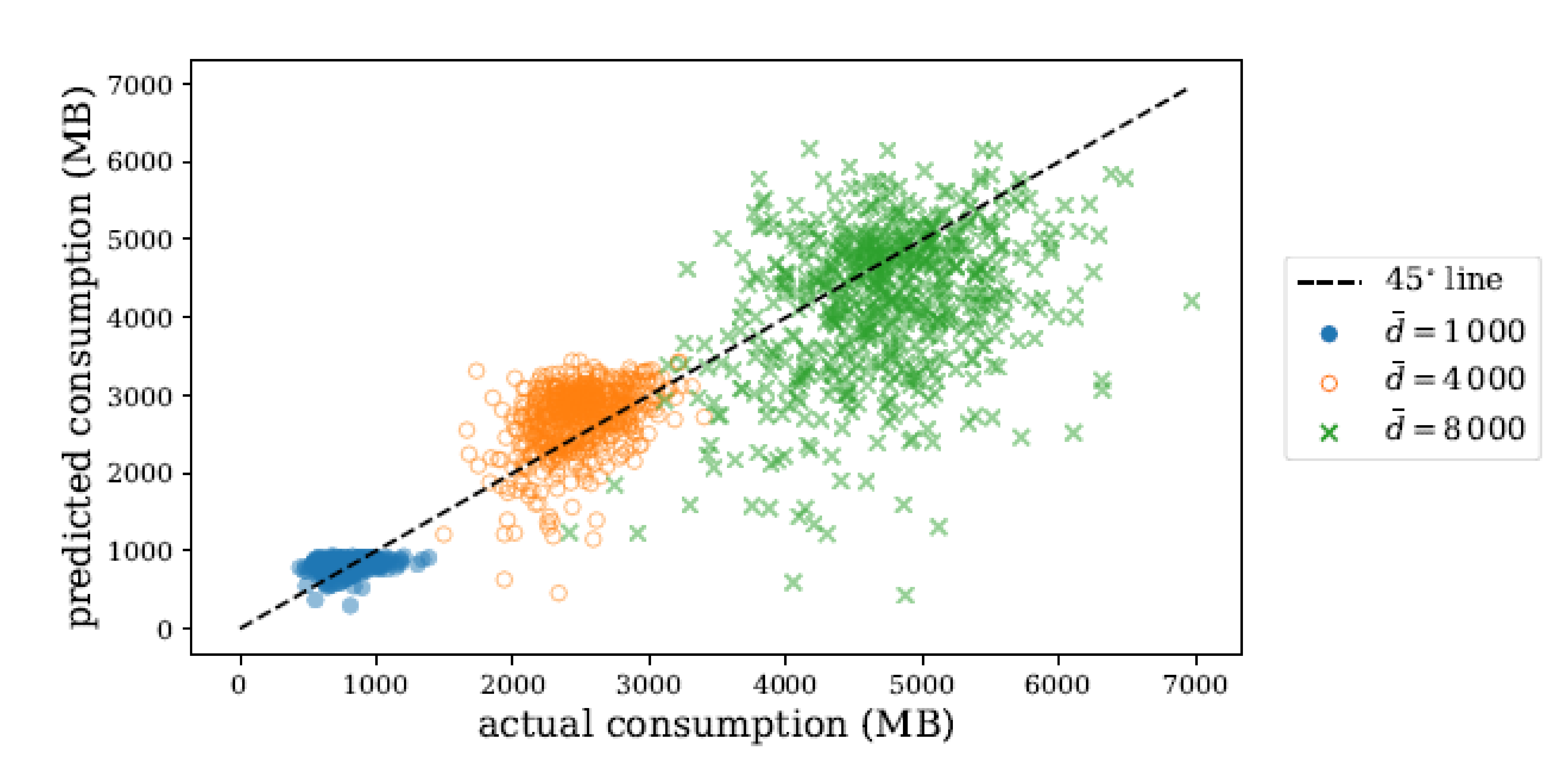
- Choice of contract:

$$j_m^*\left(\theta_i\right) = \arg\max_{j\in\mathcal{J}}\left\{\mathbb{E}\left[v\left(j,x_m^*(j;\theta_i,\zeta_i),m;\theta_i,\zeta_i,\varepsilon_{ij}\right)\right]\right\}$$

Estimation of demand model

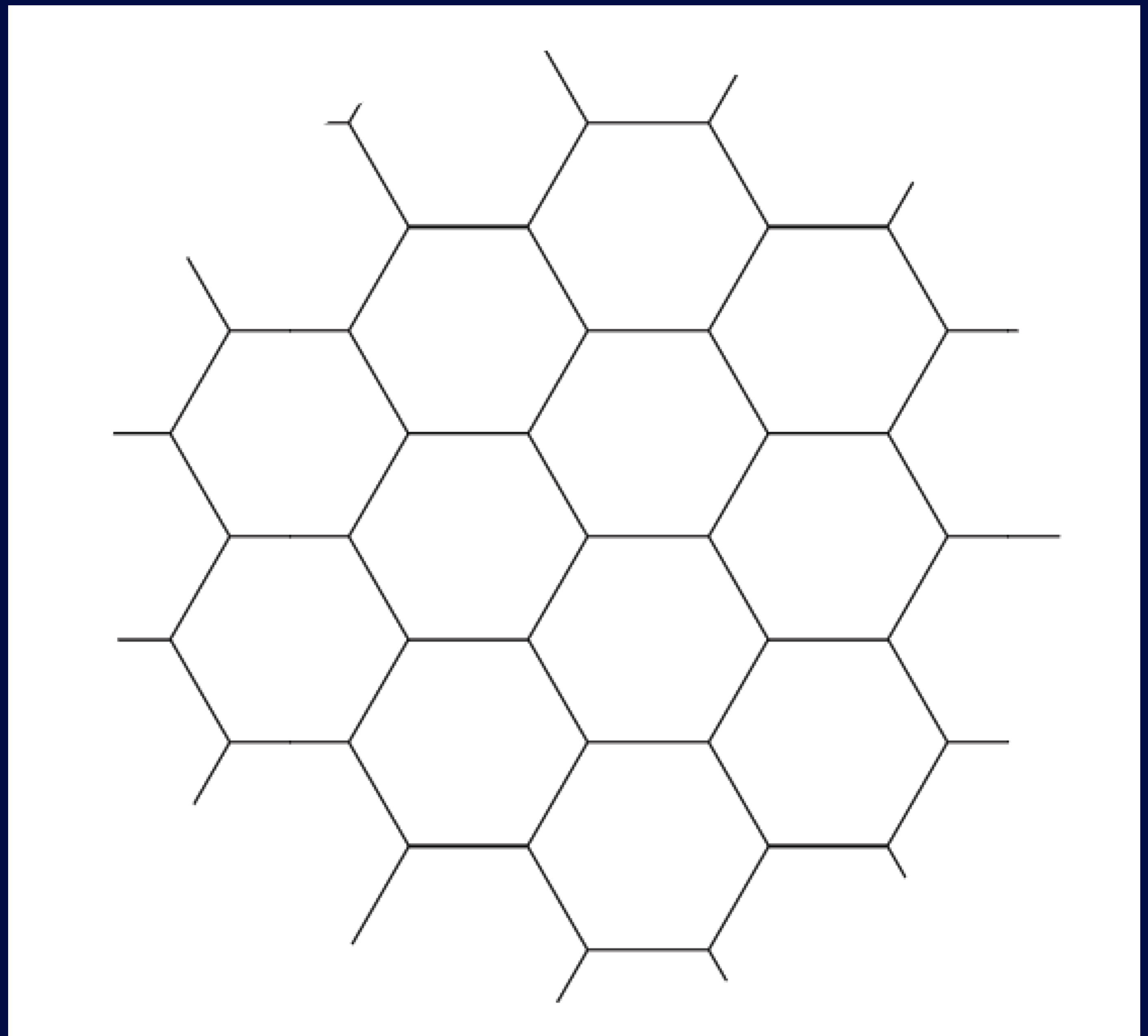
- Not much price variation
- Estimation under the constraint to recover reasonable estimates of elasticities published in the literature
- Important role of variability in market shares, income distribution and data consumption

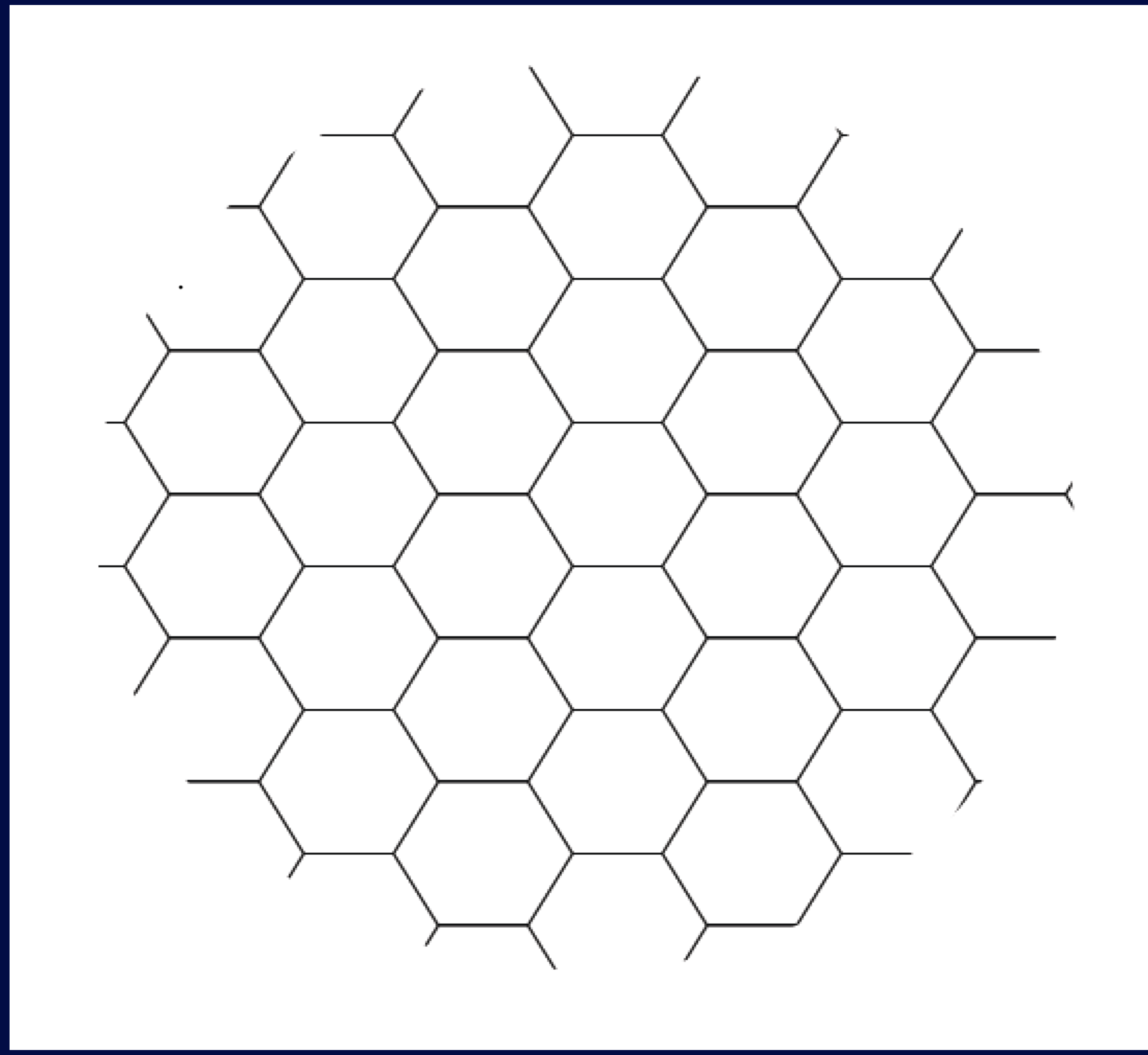
Estimation of demand model



Data transmission (Engineering model)

- Define the size of each cell (radius)
  - Given the size of a territory and the number of stations





Data transmission

- The maximum rate of data transmission is function of the radius
  - ➢ Shannon-Hartley theorem

$$q_m(r) = \gamma_m \log_2 (1 + SINR(r))$$

- The maximum download speed depends on
  - ➢ The rate of data transmission
  - ➢ The size of cells (radius)

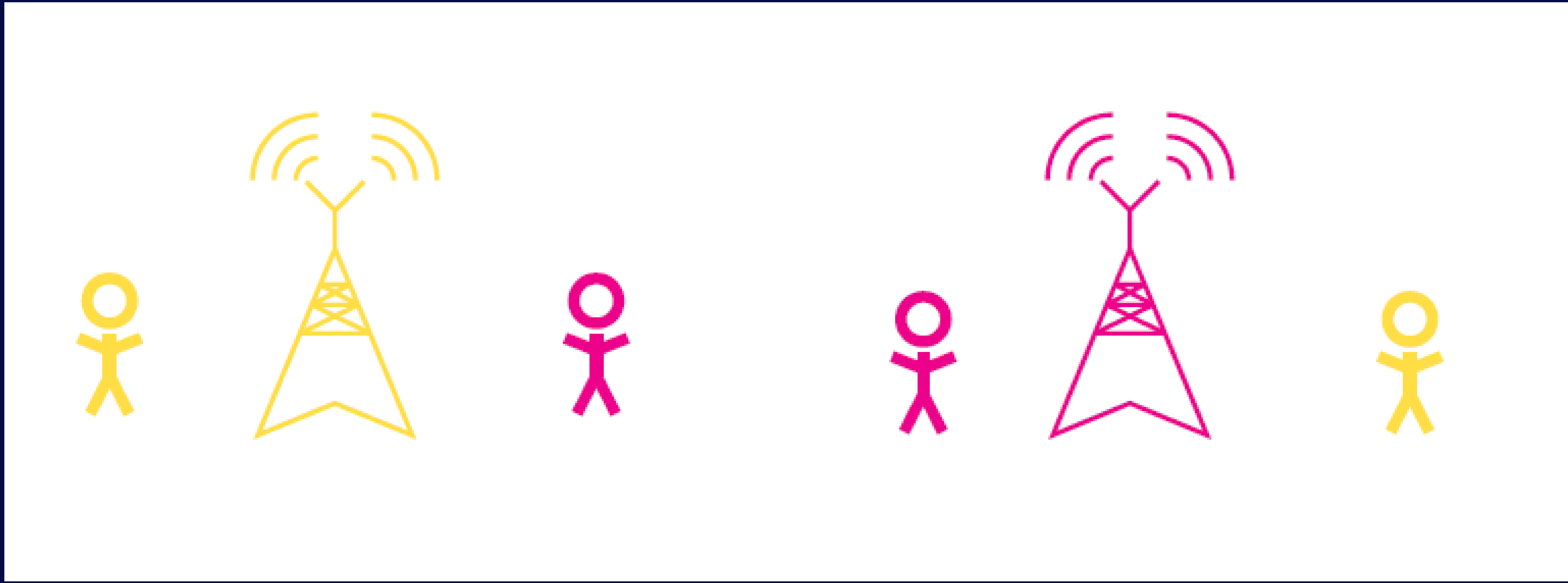
Data transmission

- The delivered download speed is the result of
  - The maximum download speed
  - The requested download speed (the observed data consumption per base station)

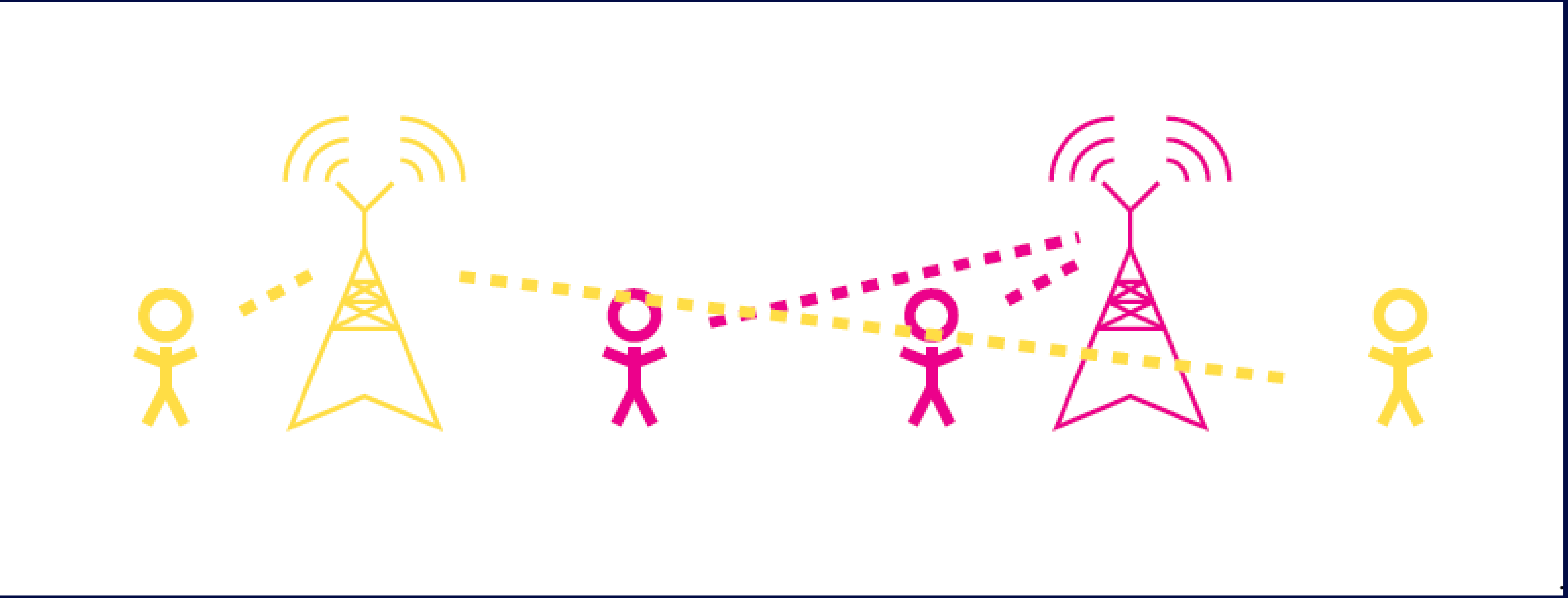
$$Q_{fm}\left(\bar{Q}_{fm}, Q_{fm}^{D}\right) = \bar{Q}_{fm} - Q_{fm}^{D}\left(\mathbf{Q}_{m}\right)$$

Economies of density

Economies of density



Economies of density



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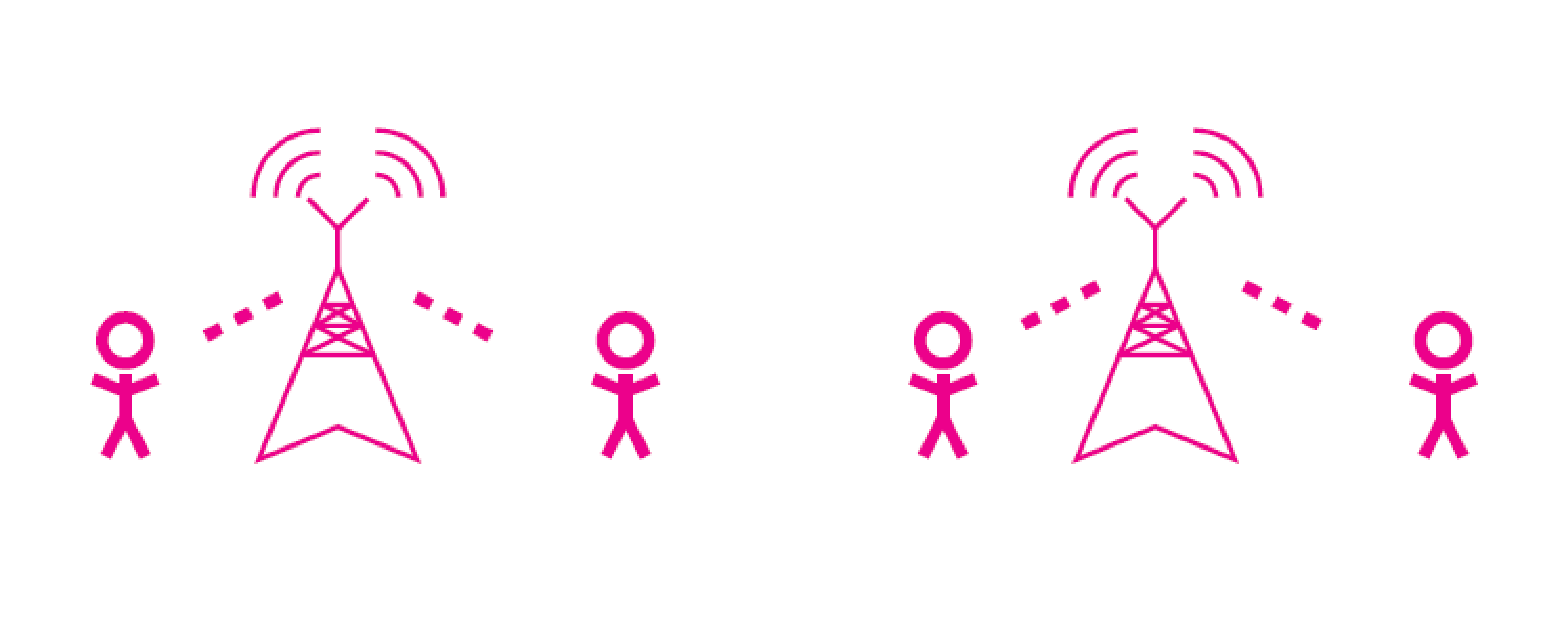
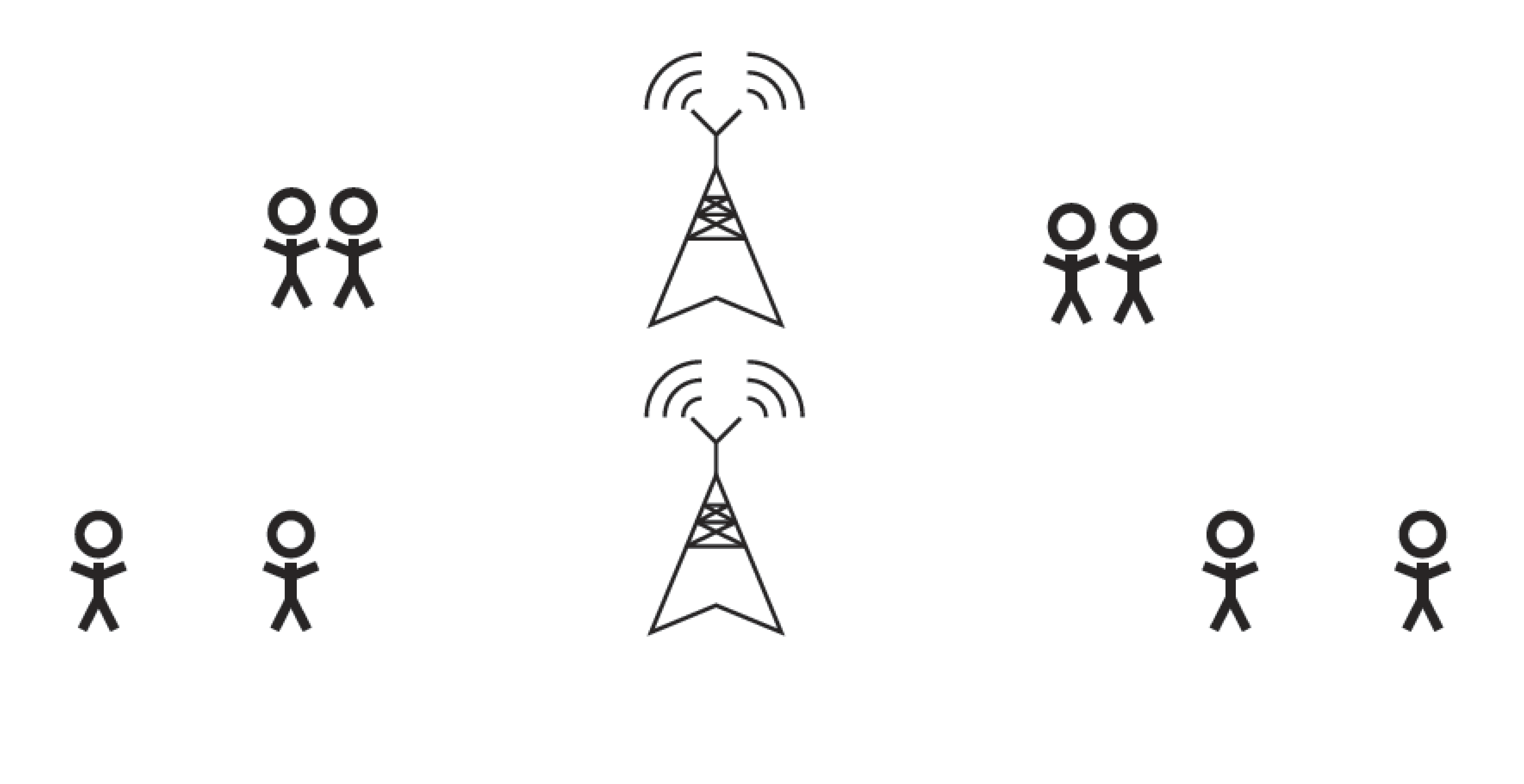
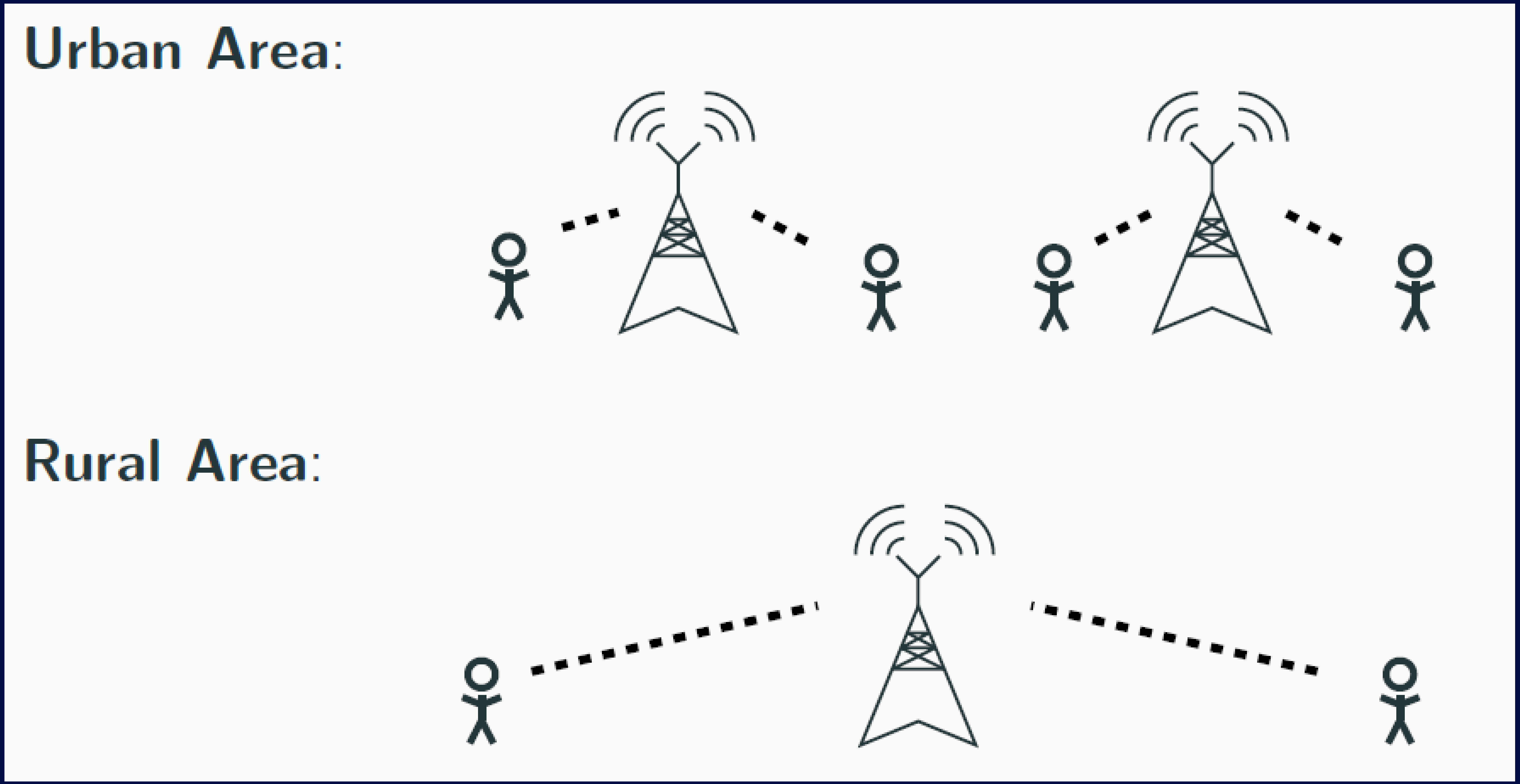


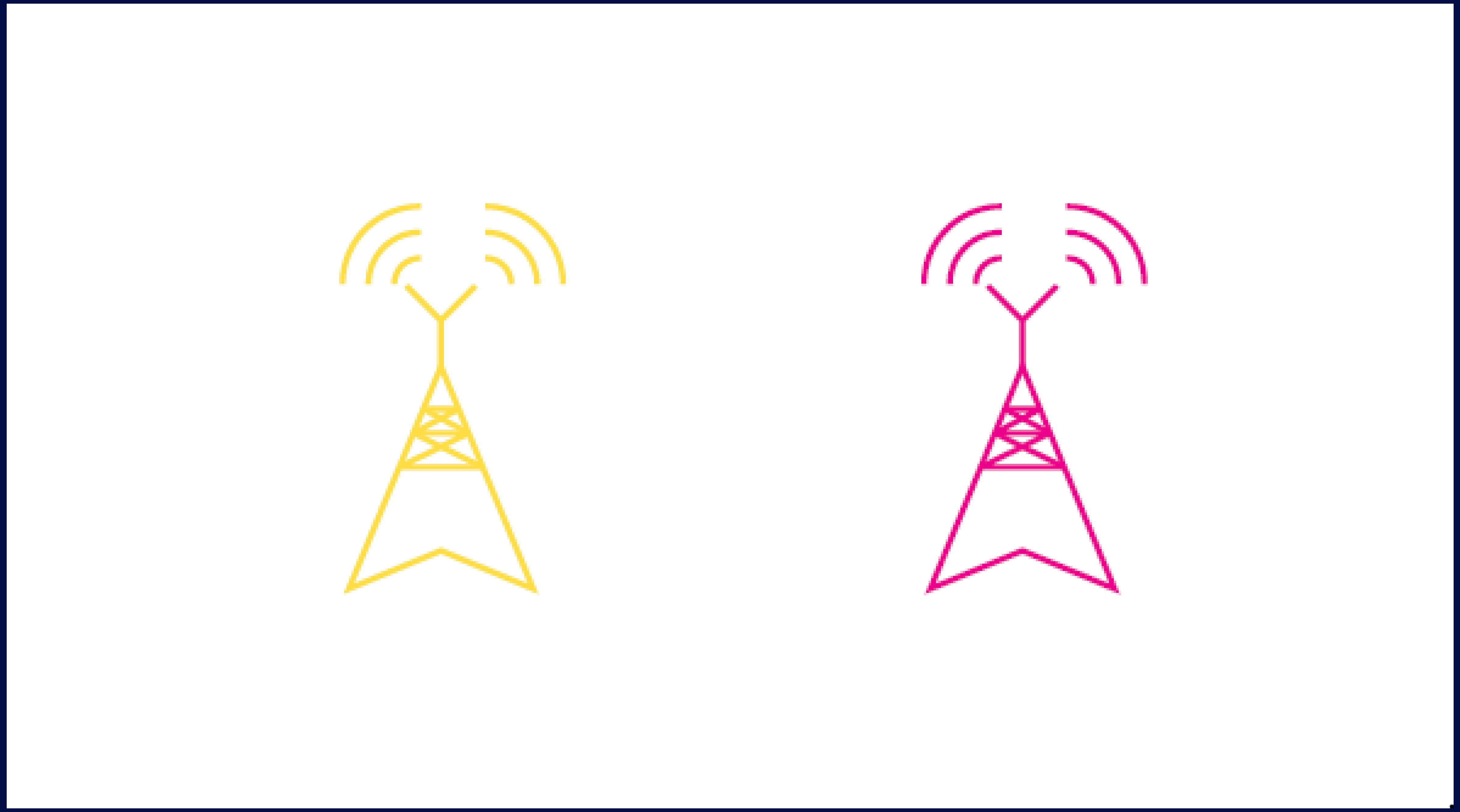
Urban vs Rural / Dense vs Scarce



Economies of density



Economies of pooling



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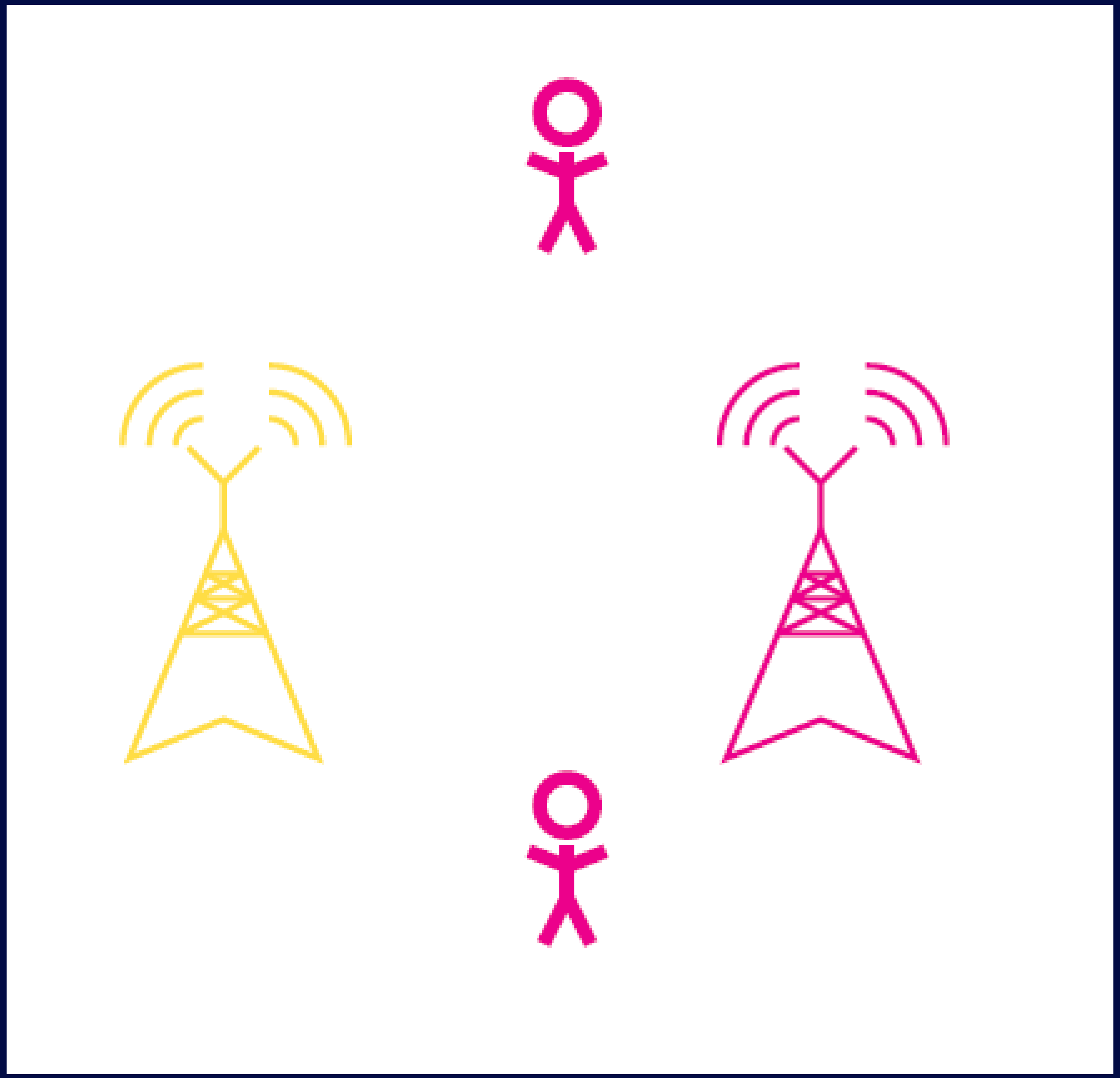

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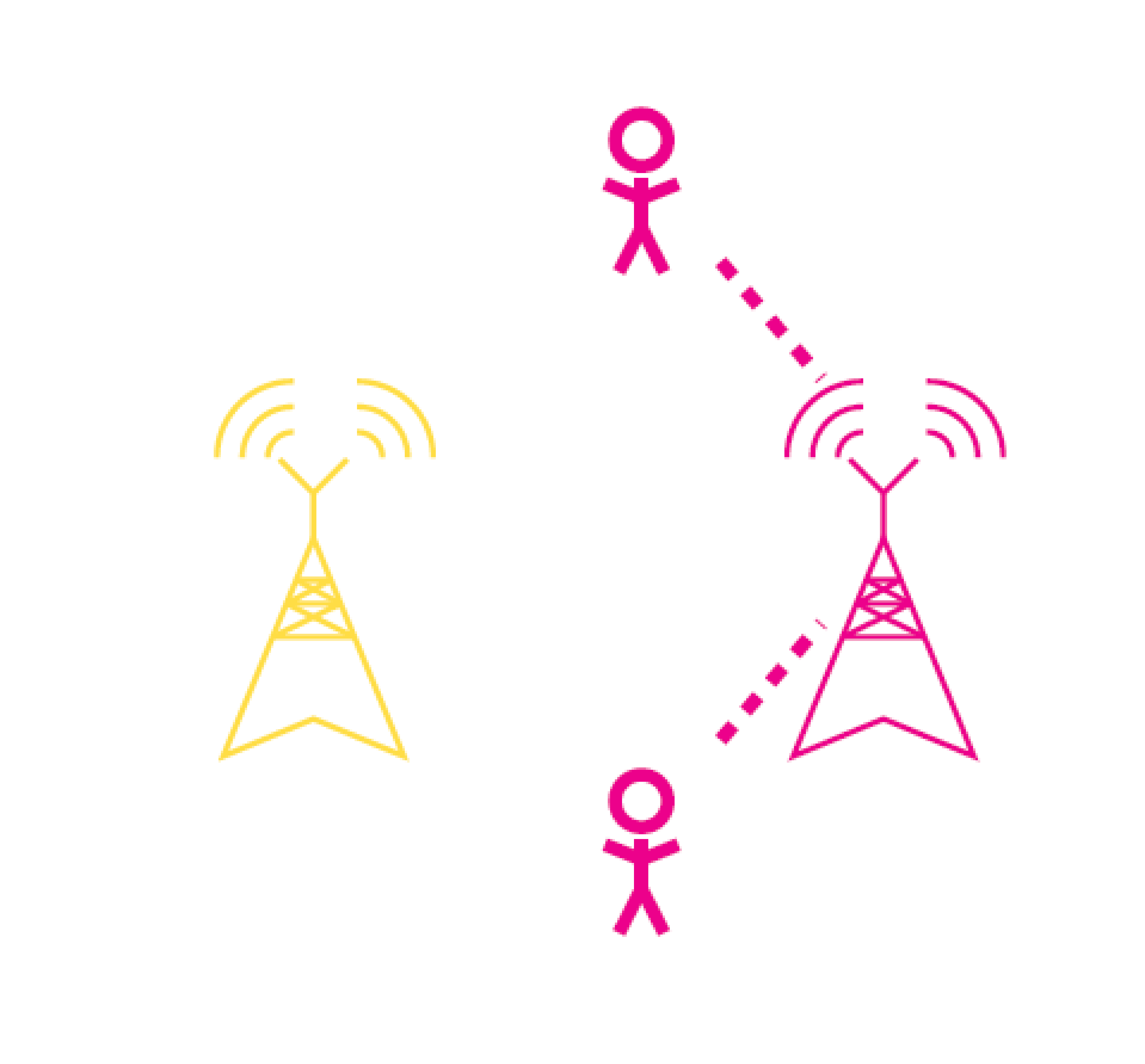

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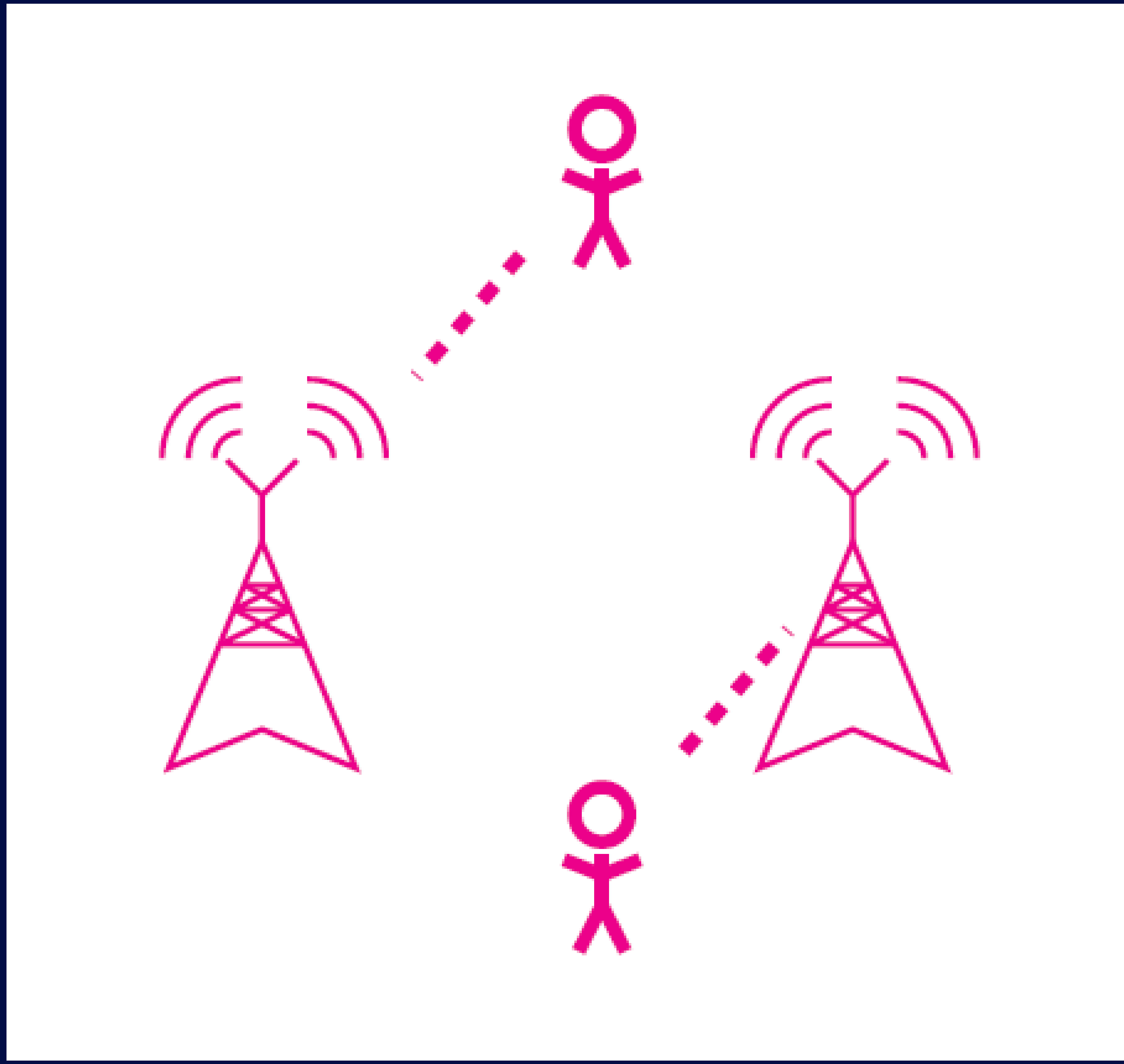


Competition in price

- Second stage
  - ➢ Choose the prices given the number of stations, download speeds and bandwith

$$\mathbf{P}_f^*(\mathbf{N}_m, \mathbf{B}) = \arg\max_{\mathbf{P}_f} \sum_m \left(\mathbf{P}_f - \mathbf{c}_f^u\right) \mathbf{s}_f\left(\mathbf{P}_f, \mathbf{P}_{-f}, \mathbf{Q}_m\right)$$

subject to

$$\forall f, m : \quad Q_{fm} = Q_{fm}\left(N_{fm}, B_f, Q_{fm}^D\left(\mathbf{P}_f, \mathbf{P}_{-f}, \mathbf{Q}_m\right)\right)$$

Competition in infrastructure

- First stage
  - Choose the number of stations given prices and download speeds

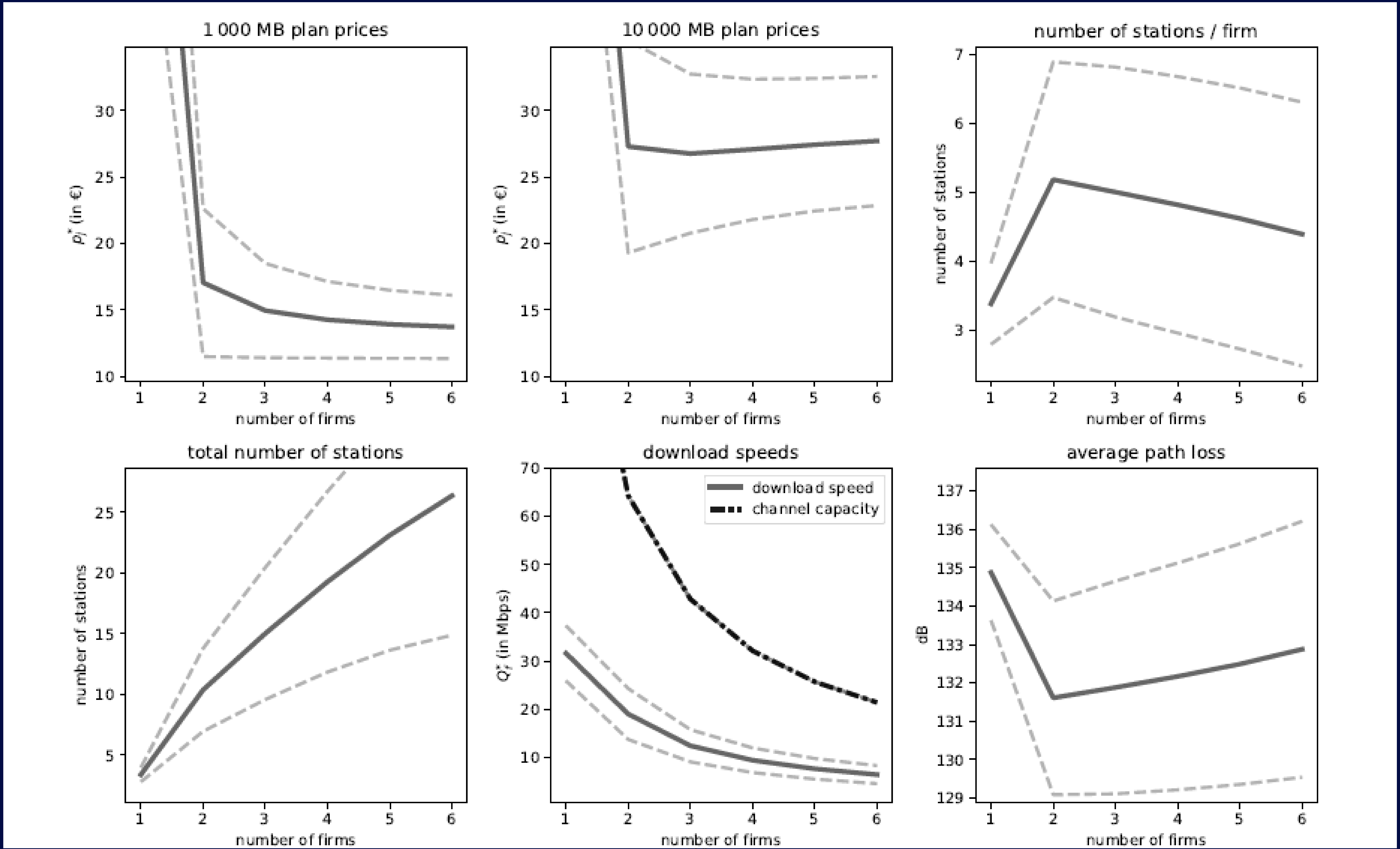
$$N^*_{fm}(\mathbf{B}) = \arg\max_{N_{fm}} \Big\{ \Pi_f \big(\mathbf{P}^* \left(N_{fm}, \mathbf{N}_{-fm}, \mathbf{B} \right), N_{fm}, \mathbf{N}_{-fm}, \mathbf{B} \big) - C_f \left(B_f, N_{fm} \right) \Big\}$$

Cost estimates

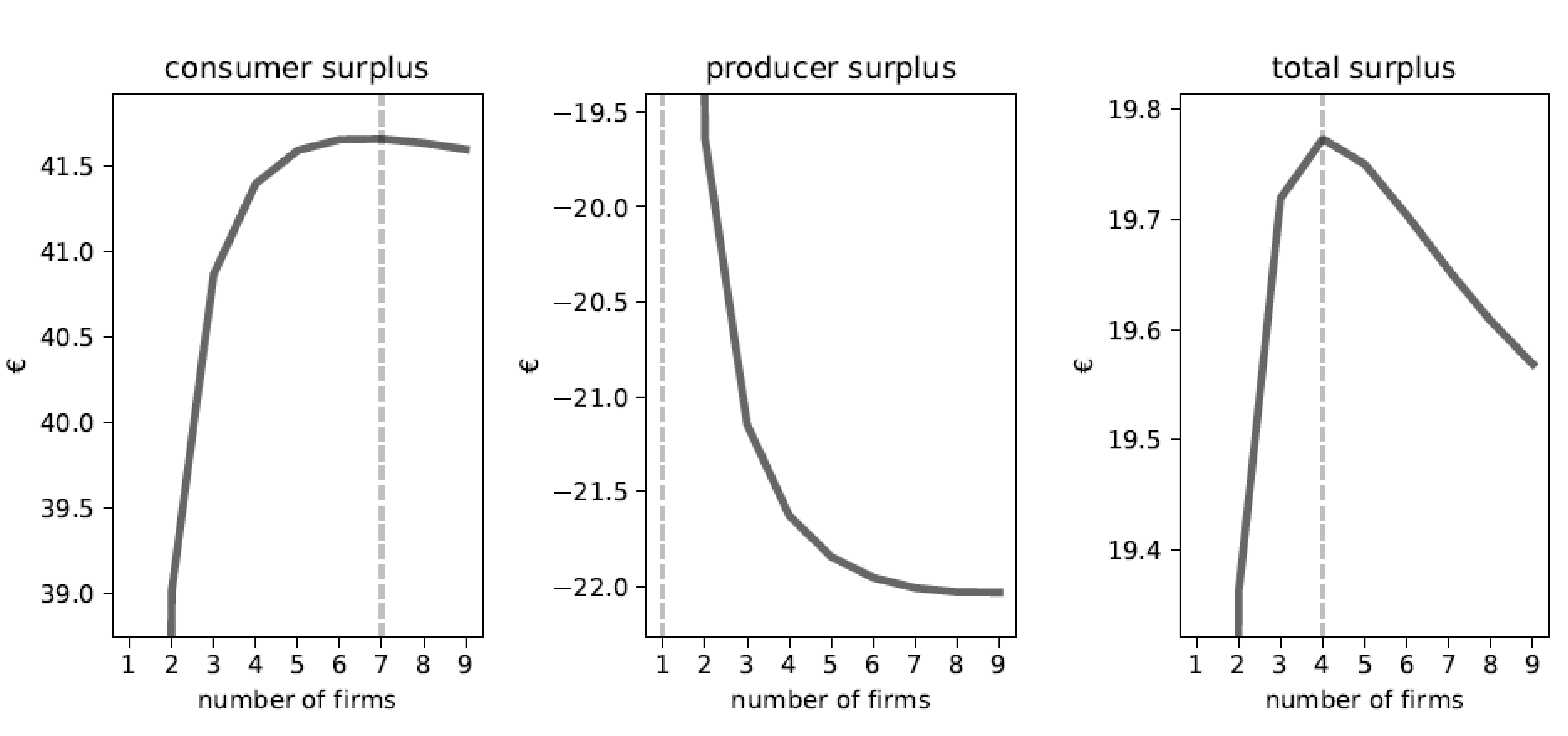
Per-user costs		$\bar{d} < 1\,000$ (in €)	$1\,000 \leq \bar{d} < 5\,000$ (in €)	$\bar{d} \geq 5\,000$ (in €)
$\hat{c}^u_j$		4.95	10.33	20.53
		(0.65)	(0.66)	(2.02)
Per-base station costs	Orange (in €)	SFR (in €)	Free (in €)	Bouygues (in €)
$\hat{C}_f$	182 197	140 556	142 792	201 733
	(60 698)	(40 035)	(46 587)	(67 896)

Simulation: Optimal Number of Firms

- Increase the number of operators assuming a symmetric distribution of bandwidth
  - Reprentative contracts
  - Representative territory (not much effect of the density)

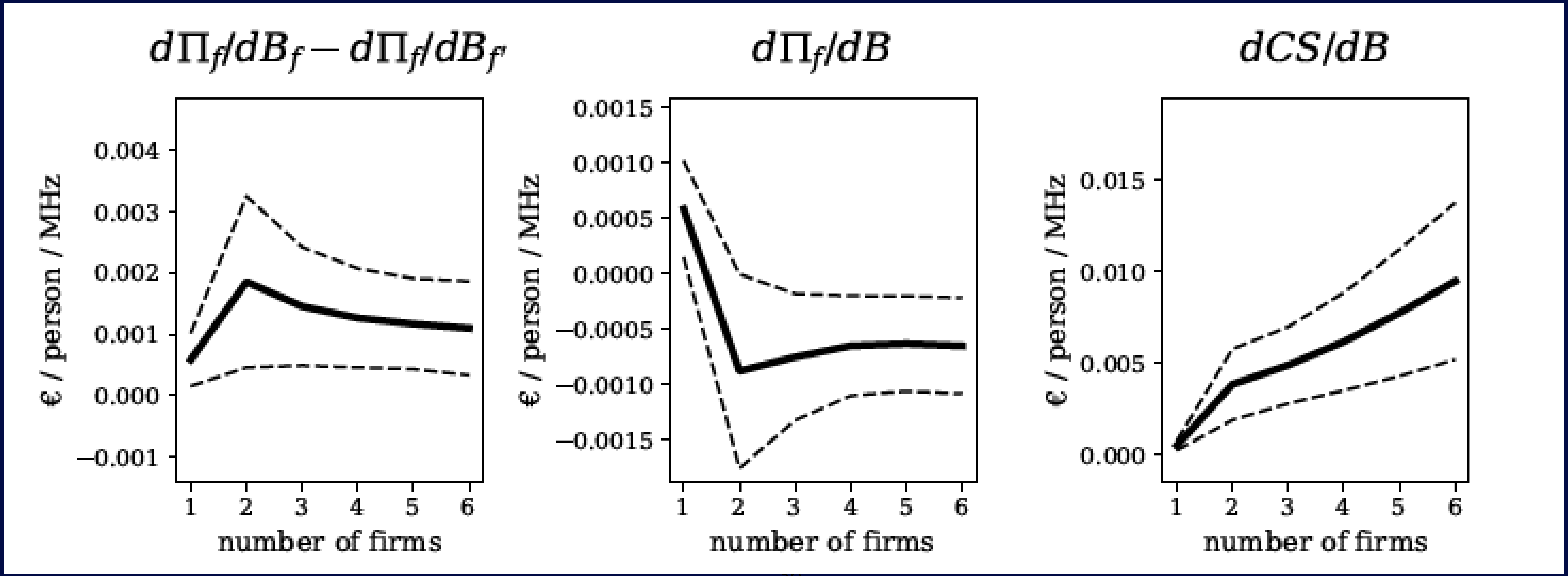


1 000 MB plan prices
10 000 MB plan prices
number of stations / firm
total number of stations
download speeds
average path loss
download speed
channel capacity
number of firms
number of stations
dB


consumer surplus
producer surplus
total surplus
€
41.5
41.0
40.5
40.0
39.5
39.0
−19.5
−20.0
−20.5
−21.0
−21.5
−22.0
19.8
19.7
19.6
19.5
19.4
1 2 3 4 5 6 7 8 9
number of firms

Simulation: Social Value of Spectrum

- WTP for spectrum = 5 times lower than its social value



Impact of network sharing

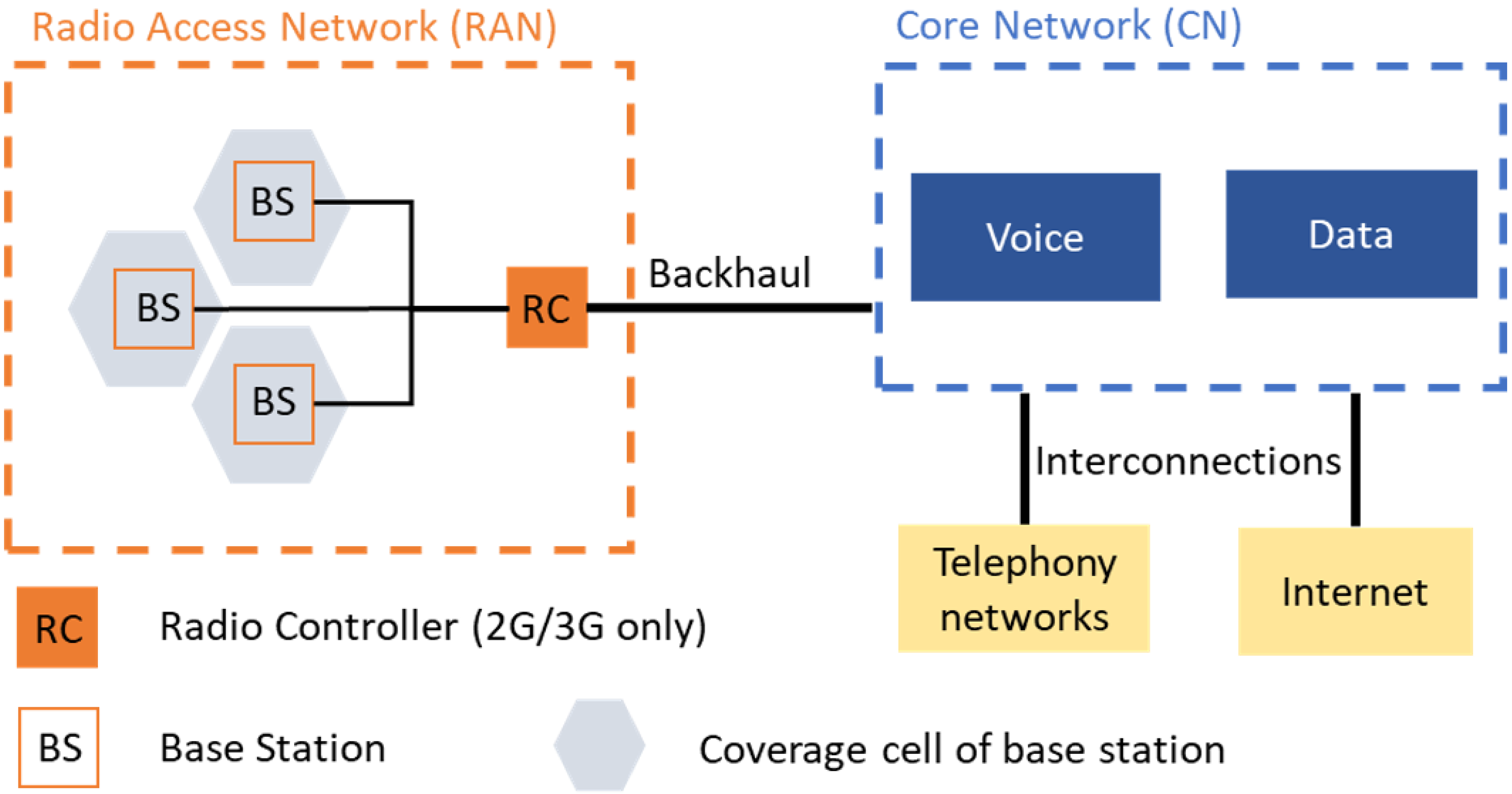
Based on

Case AT.40305 Network Sharing Czech Republic

- *Economic studies with NERA Economic Consulting*

Mobile Telecommunications Network

The technology



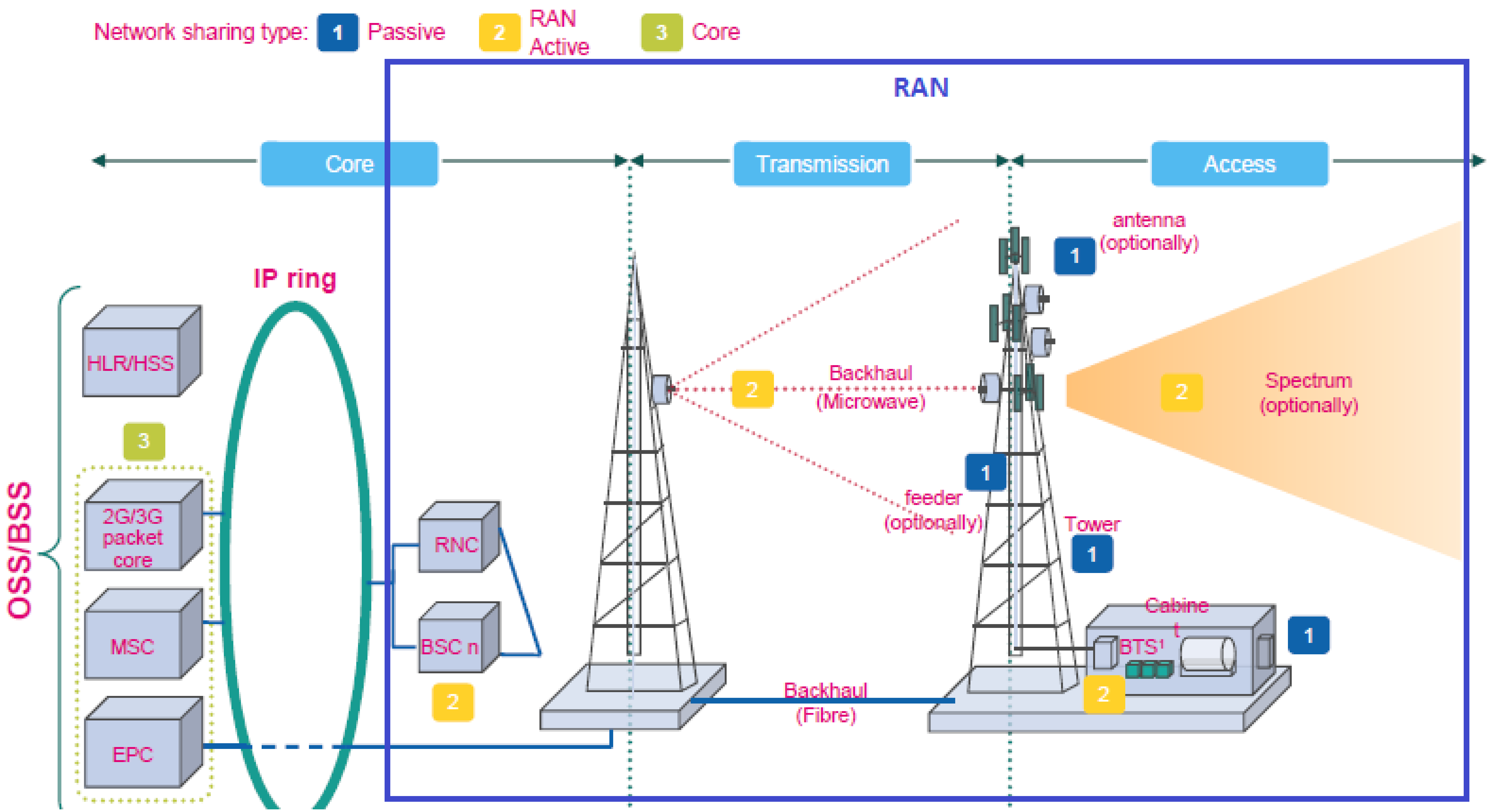
The roll-out of mobile telecommunications networks

With increased demand for data intensive services

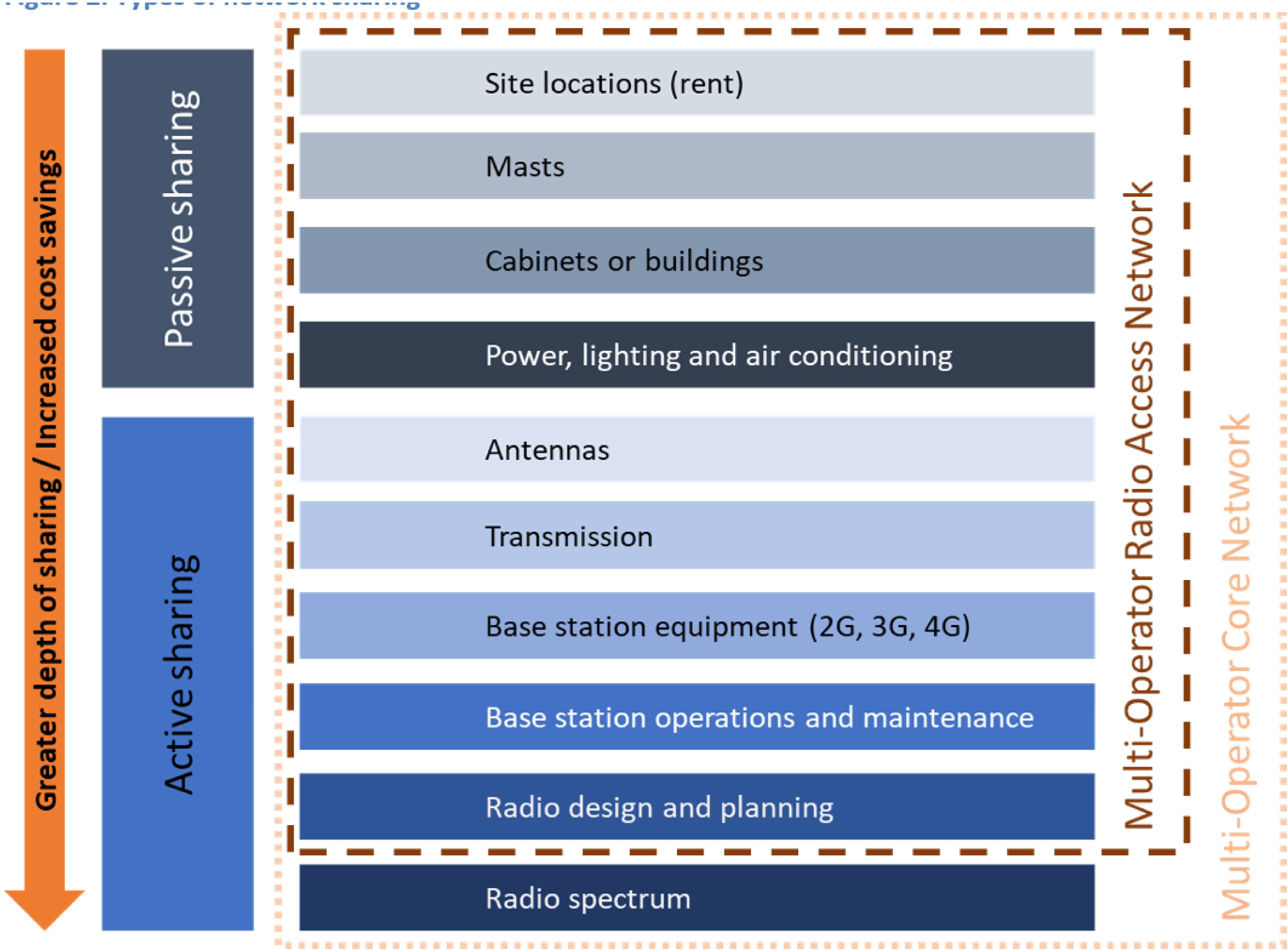
1. Full deployment of the spectrum
2. Use other capacity-enhancing technologies
3. Increase the number of base stations (ie, densify the network)
   - Costly
   - Write Network Sharing Agreement
     - Different levels of network sharing
     - Different ways to deploy and operate the network

Network Sharing Agreement

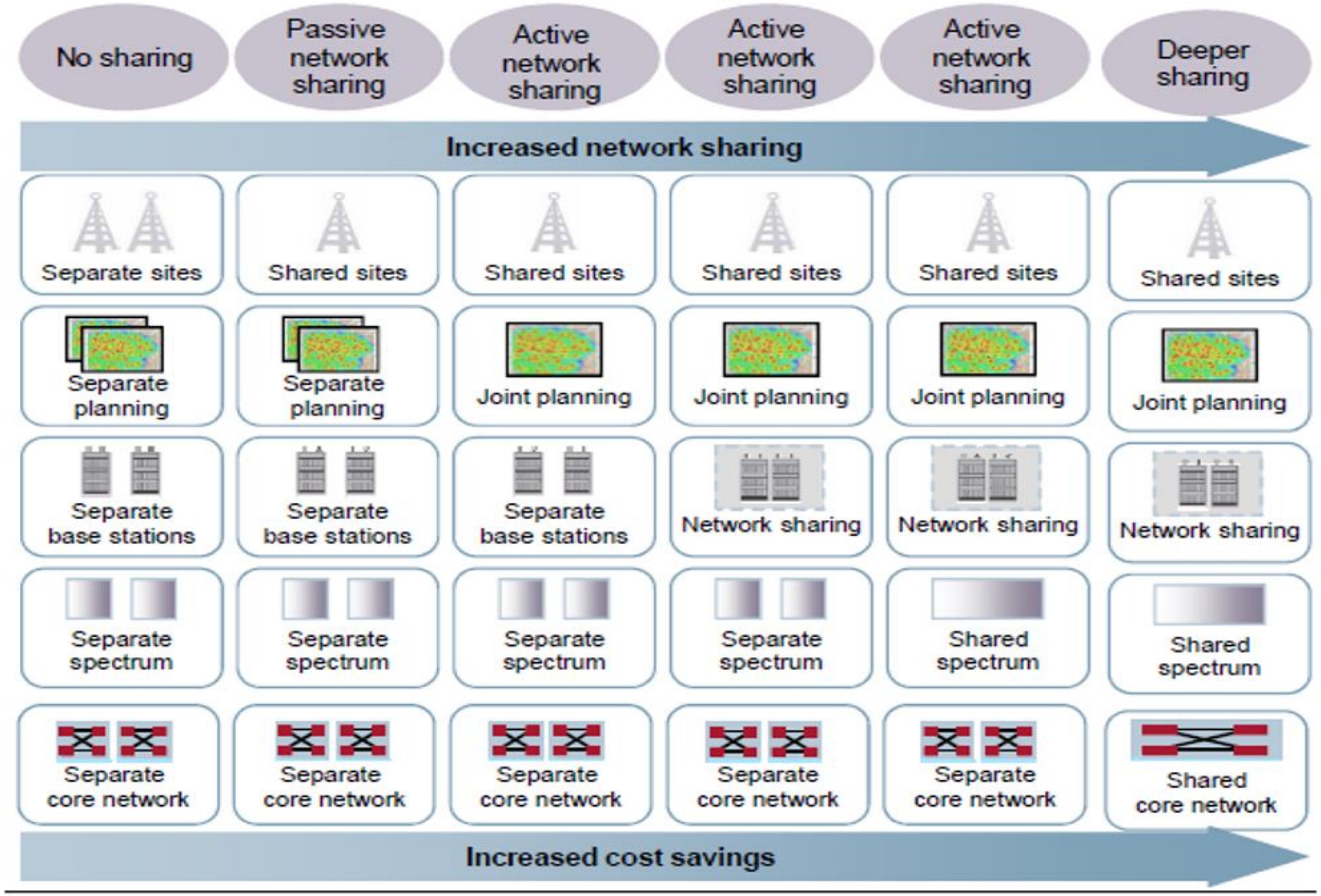
The technology concerned by the NSA



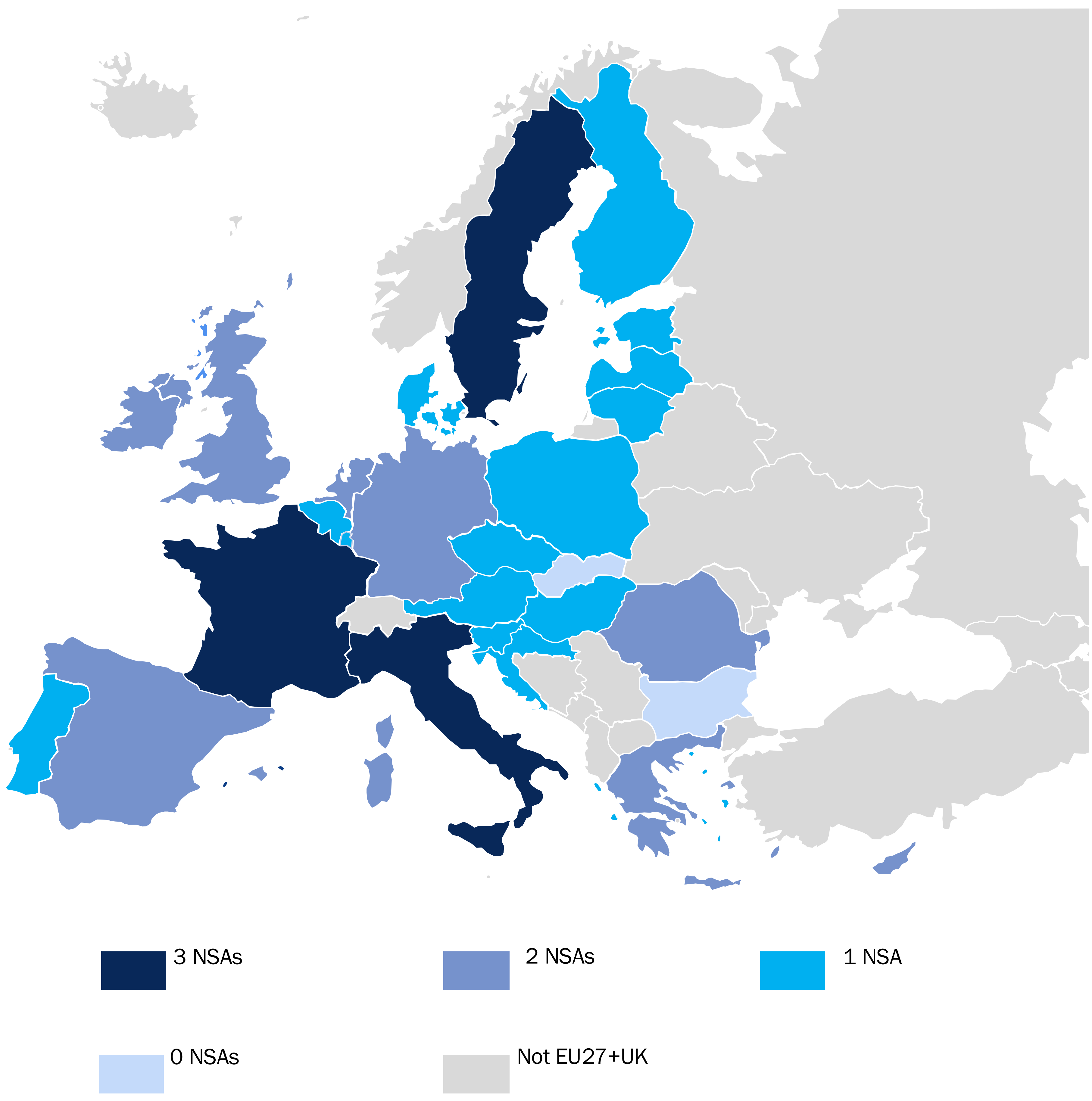
The technology and the type of NSA

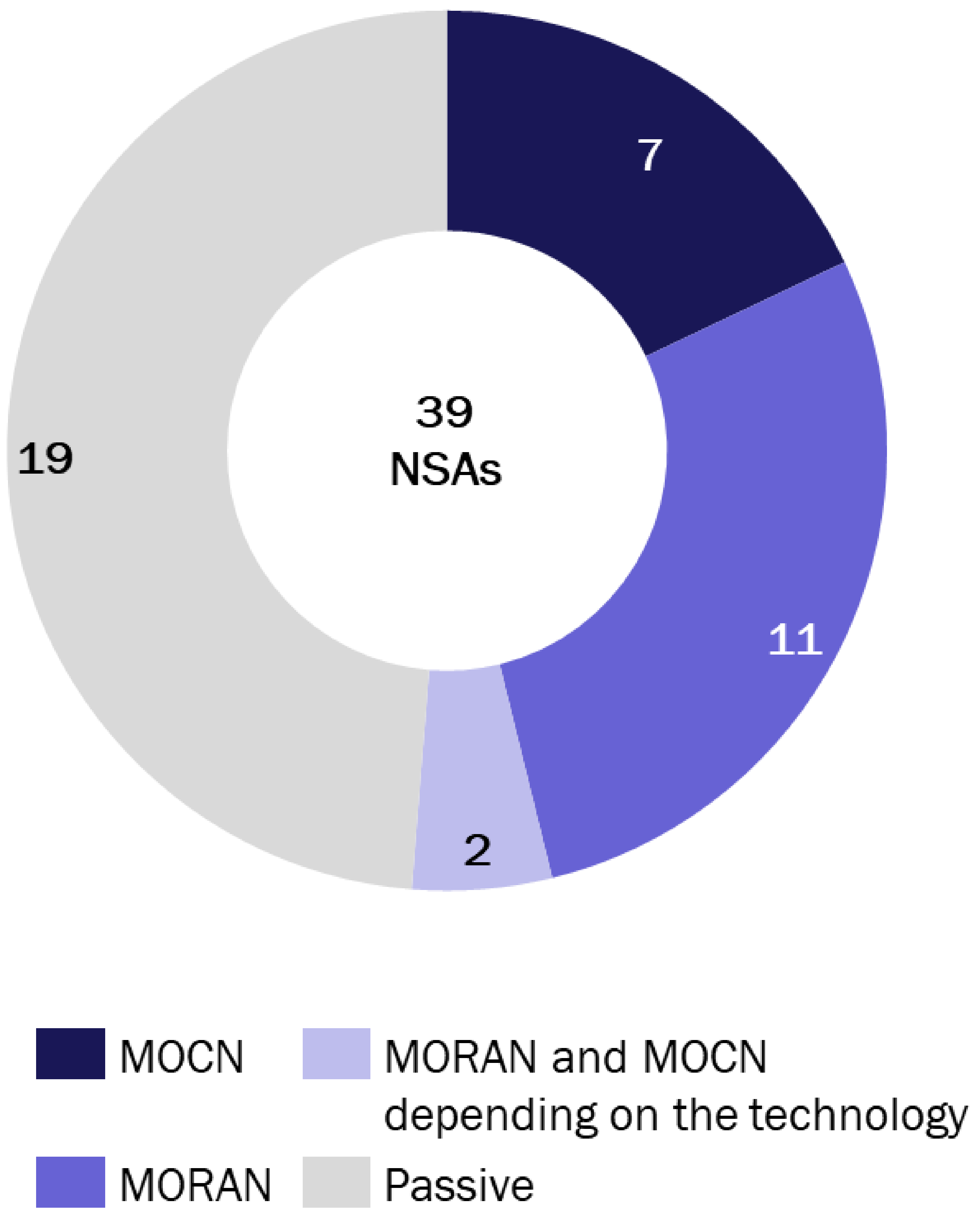


The technology and the type of NSA



NSA in Europe

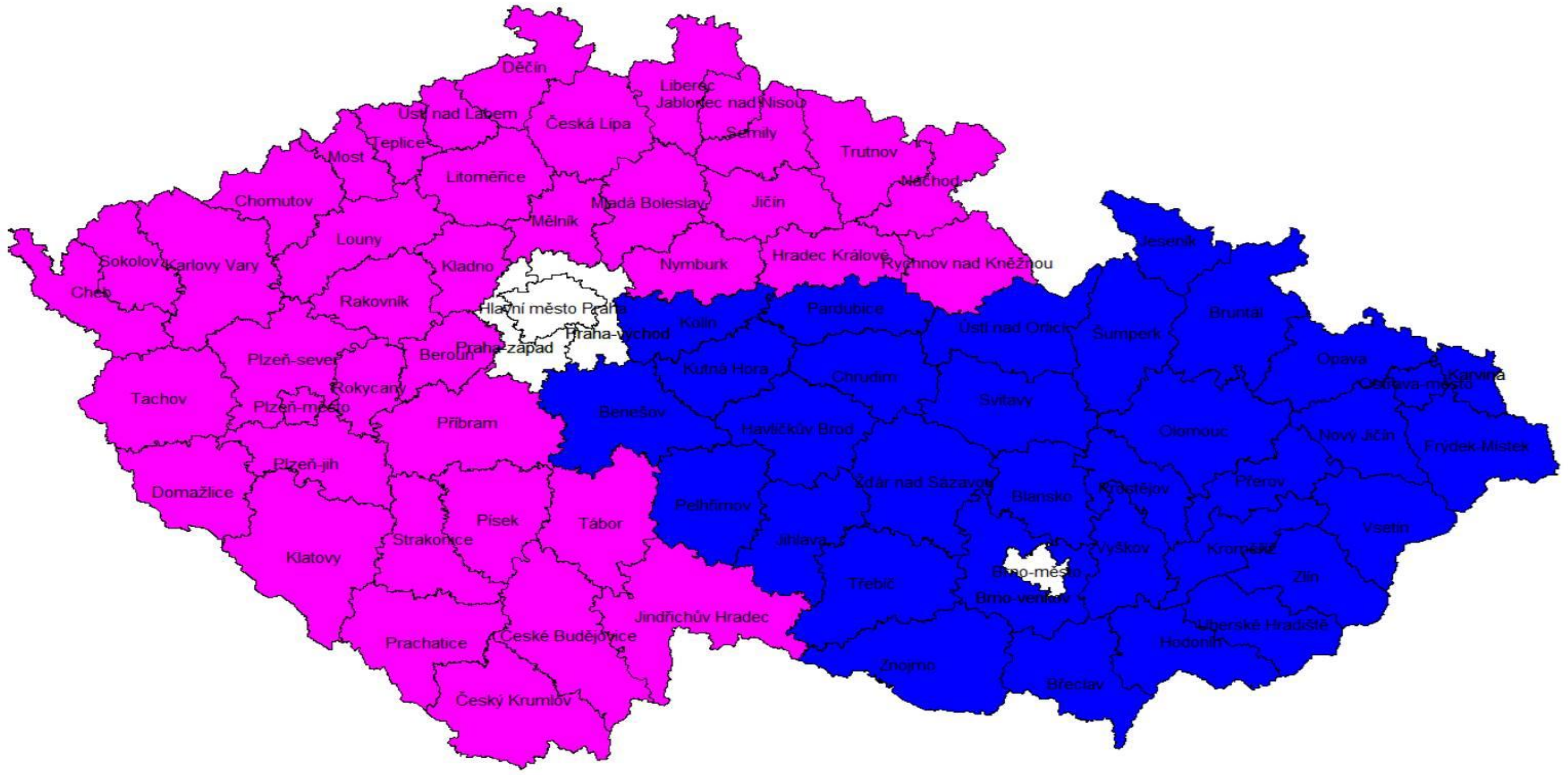




MORAN: Multi-Operator Radio Access Network
MOCN: Multi-Operator Core Network

The NSA in Czech Republic

- 3 MNOs (= 99% of the market)
  - O2 - TM – Vodafone
- Passive and active sharing between O2 and TM
  - 2G/3G agreement in October 2013
  - 4G/LTE agreement in May 2014
- Geo-split



The scope for an economic analysis

Effects of NSA on prices, quality and consumer welfare

- Issues
  - Cooperation on investment → Impact on quality and prices
  - Competition on prices and quality → Impact on investment
- Questions
  - Does cooperation driving the market away from the competitive outcome?
  - Is the NSA welfare enhancing compared to a counterfactual without NSA?

Potential pro-competitive effects

No Duplication of Infrastructure
Lower cost of infrastructure

Passthrough
Lower prices

Denser networks
Higher quality

Potential pro-competitive effects

Similar network quality

More intense price competition

Lower prices

Potential anti-competitive effects

- Exchange of information → Co-ordination for higher prices
- Negotiation on technologies → Lower network quality
- Geographic impact
  - Less densely versus high densily areas

Effect of CZ NSA on prices

Methodology

- Benchmarking (DiD) on the expenditure on baskets of telecoms services
  - CZ versus European countries with no NSA

- Quarterly data from Teligen database from 2010 to 2019
  - Tariffs of two biggest MNOs per country for 36 countries

OECD (2010, 2012) Usage Basket Volumes for Monthly Consumption

Basket Name	Calls	SMS	Data
			----(Mb)----
OECD1	30	100	100
OECD2	100	140	500
OECD3	300	225	1,000
OECD4	900	350	2,000
OECD5	100	140	2,000

Source: OECD (2010, 2012).

Model

$$\log(p_{c,o,i,t}) = \alpha + \beta D_{CZ} + \gamma NSA_{2014Q1} + \delta_1(D_{CZ} * NSA_{2014}) + \delta_2(D_{CZ} * NSA_{2015}) + \delta_3(D_{CZ} * NSA_{2016}) + \delta_4(D_{CZ} * NSA_{2017}) + \delta_5(D_{CZ} * NSA_{2018}) + \delta_6(D_{CZ} * NSA_{2019Q1-Q2}) + \lambda_1 \Delta GDP_{c,t} + \lambda_2 logMRT_{c,t} + \mu_c t + \sum_{c'o' \in E \otimes \Omega} \mu_{c'o'} D_{c'o'} + vD_{2012Q1} + \theta_t Q + \varepsilon_{c,o,i,t}$$

where for country c, operator o, tariff i at period t:

- $\log(p_{c,o,i,t})$ is the logarithm of the RBE;
- D_{CZ} is the Czech Republic fixed effect;
- NSA_{period} is the NSA fixed or time-specific effect, taking the value 1 from the specified *period* onwards;
- $D_{CZ} * NSA_{year}$ is the treatment, i.e., the Czech Republic NSA effect for *year;*
- $\Delta GDP_{c,t}$ is the growth rate of the GDP per capita;
- $logMRT_{c,t}$ is the logarithm of MTR;
- $\mu_c t$ is the country-specific time trend;
- $\sum_{c'o' \in E \otimes \Omega} \mu_{c'o'} D_{c'o'}$ is the country-operator fixed effect, where:
  - Ω: The set of operators;
  - E: The set of countries in the treatment and control groups.
- D_{2012Q1} is a dummy variable for the period Q1-2012 (which corresponds to the introduction of the data component in tariffs included in the Teligen dataset); and
- $\theta_t Q$ is the quarter-specific effect.

–The effect of the NSAs on prices in the Czech Republic
–The overall evolution of prices in the Czech Republic
–The overall evolution of counterfactual prices (i.e., prices in the countries of the control group)
–Demand and supply changes that impact both prices in the Czech Republic and the counterfactual prices
–The heterogeneity between operators and the prices that they charge

Results

Resulting RBE change for the main specification

Basket	OECD1	OECD2	OECD3	OECD4	OECD5
Year:			%		
2014	-17.35***	-16.96***	-18.36***	-20.68*	-19.56***
2015	-17.58***	-27.2***	-24.55***	-34.61***	-26.19***
2016	-25.29***	-30.33***	-18.48**	-29.41**	-28.21**
2017	-38.45***	-30.38***	-10.27	-19.5	-29.68**
2018	-45.25***	-33.65***	-2.91	-13.63	-34.22**
2019 Q1-Q2	-43.91***	-39.19***	-4.96	-18.28	-40.9**

Effect of CZ NSA on quality

Methodology

- Change in quality index before & after the NSA
  - Download speed
  - Upload speed
  - Latency

- Quaterly data from Ookla database from 2010 to 2019

- DID analysis not implementable
  - Possible candidates for control group
    - Vodafone but impacted by the NSA
    - Prague and Brno but cannot allow to disentangle NSA and 4G effects

Model

$$\ln(quality_{d,o,t}) = \alpha + \beta_1 * NSA_{2014Q1} + \beta_2 * capacity\ 2G_{d,o,t} + \beta_3 * capacity\ 3G_{d,o,t} + \beta_4 * capacity\ 4G_{d,o,t} + \beta_5 * unemployment_{d,t}\beta_6 * \ln(ARPU_{o,t-1}) + \beta_7 * \ln(subscribers_{o,t-1}) + \beta_8 * \ln(data\ traffic_{t-1}) + Trend_t + Trend^2{}_t + D_{area} + D_d + D_o + \varepsilon_{d,o,t}$$

where for district *d*, operator *o* at time *t:*

- $\ln(quality_{d,o,t})$ is the logarithm of quarterly network quality by district and operator, measured by either download speed, upload speed or latency;
- NSA_{2014Q1} is a dummy variable equal to 1 post 2G/3G NSA (Q4-2013) and zero otherwise in the 2G/3G NSA regressions;
- $Capacity\ 2G_{d,o,t}, Capacity\ 3G_{d,o,t}, Capacity\ 4G_{d,o,t}$ are the annual sums of deployed spectrum of the respective technology by district and operator;
- $Unemployment_{d,t}$ is the annual unemployment rate by district;
- $\ln(ARPU_{o,t-1})$ is the natural logarithm of the one-period lagged quarterly average revenue per user by operator;
- $\ln(Subscribers_{o,t-1})$ is the natural logarithm of the one-period lagged quarterly number of active subscribers by operator;
- $\ln(data\ traffic_{t-1})$ is the natural logarithm of the one-period lagged total data traffic in the Czech Republic;
- $Trend_t$ is a linear trend variable;
- $Trend_t^2$ is the square of the linear trend variable;
- $D_{area}$are the area fixed effects (Prague & Brno, East, West);
- D_d are the district fixed effects;
- D_o are the operator fixed effects.

Results

After the NSAs :

–Download speed increased on average between 22 and 26%

–Upload speed increased on average between 52 and 62%

–Network latency decreased on average between 27 and 30%

Effect of CZ NSA on consumer welfare

Methodology

- A price-quality strategic model with differentiated products
  - Hypothesis: Static equilibrium
    - Investment is exogenous
    - Investment affects access and quality costs
  - Possible equilibria

A strategic model in prices and quality

- Possible equilibria
  - Timing
    - Simultaneous: price and quality are simultaneously chosen
    - Sequential: quality first and then price
  - Behavior
    - Competition in price and quality
    - Coopetition (Hybrid)
      - Cooperation on quality
      - Competition on prices

Demand

- A nested logit demand model

$$ln\left(\frac{s_{it}}{s_{0t}}\right) = \mu_0 + \beta q_{it} - \alpha p_{it} + \sigma\, ln(\, s_{i|gt}) + x_{it}\delta + \xi_{it}$$

- Probability to access network of operator *i*
  - Measured by the market share of operator in terms of number of subscribers per operator per year

- Products
  - O2, TM, VOD (Vodafone)
  - Outside good

- Market size
  - Twice the Czech population of 16 years or older
    - Observed penetration rate of wireless services in CZ above 140 %

Demand

- Trade-off quality – price
  - A representative user is willing to pay €0.66 for one additional Mbit/s of download speed
- Price elasticities

Own and cross-price elasticities of demand

Operator	NSA	Own price elasticity	Cross price elasticity with respect to a price change by		
			TMCZ	O2	Vodafone
O2	Before	-1.95	1.12	-	0.71
TMCZ	Before	-1.92	-	1.14	0.71
Vodafone	Before	-2.50	1.12	1.14	-
O2	After	-1.47	0.86	-	0.55
TMCZ	After	-1.39	-	0.85	0.55
Vodafone	After	-1.98	0.86	0.85	-

Supply

- Operating profits of each MNO

$$\pi_{it} = (p_{it} - c_{it})s_{it}N_t - k_{it}q_{it}^2 - K_{it}$$

  - Variable cost
    - Constant marginal cost of access
    - Variable marginal cost of quality

  - Fixed cost

Supply

- Write the FOCs associated to
  - Competition equilibrium
  - Coopetition (or hybrid) equilibrium

- Recover marginal costs
  - Access
  - Quality

- Determine how costs are affected by the NSA

Cost models

- Marginal cost of access

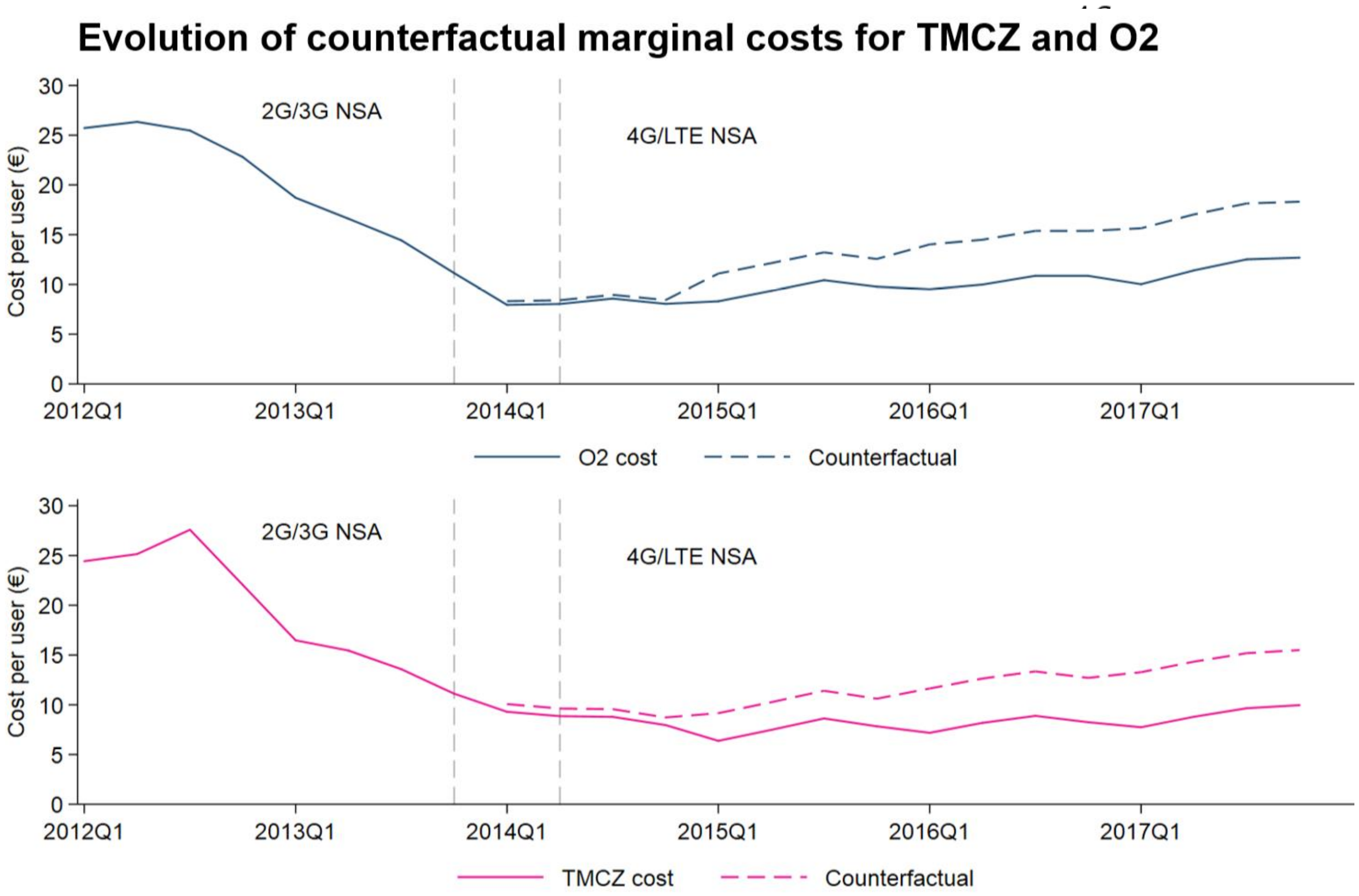
$$c_{it} = c_0 + \theta_i \mu_i + \gamma\ year_t + \phi\ quarter_t$$
$$+\rho^{shared} shared\_sites_{it}^{4G} + \rho^{nonshared} nonshared\_sites_{it}^{4G} + MTR_t + \omega_{it}$$

- Quality cost parameter

$$k_{it}^{T} = c_0 + \theta_i \mu_i + \gamma year_t + \rho^{shared} shared\_sites_{it}^{4G}$$
$$+ \rho^{nonshared} nonshared\_sites_{it}^{4G} + MTR_t + \omega_{it}$$

Simulation

- Marginal cost of access absent of NSA



Counterfactual results with no NSA

Average quarterly change (absolute and in percentages) in price, network quality and consumer surplus in the counterfactual scenario

	Scenario I		Scenario II		Scenario III	
	Abs.	%	Abs.	%	Abs.	%
Price (€)	+2.1	+6.7	+4.3	+13.5	+4.4	+13.9
Quality (Mbits/s)			-0.9	-4.2	-5.2	-24.2
Consumer surplus (Mn €)	-37.5	-2.0	-69.5	-3.7	-111.1	-5.9

Impact of shared infrastructure in terms of connectivity and inclusion

Based on

"The impact of Shared Telecom Infrastructure on Digital Connectivity in Developing Countries"

Co-authored with G. Houngbonon, E. Palikot and D. Stusani

The towerco business model

- A ‘‘tower’’ company builds and owns the infrastructure
  - Example: Joint venture of telecom service providers

- The telecom service providers have commercial contracts with the towerco

The towerco business model is
gaining momentum across developing countries
In 2020
three in four mobile towers in emerging markets
are managed by towercos

Methodology

- Data on 137 developing countries (2008 – 2020)

- Dependent variables:
  - **Availability of connectivity**: % of population covered by at least 3G/4G network (GSMA)
  - **Affordability of connectivity**: Price of mobile telephony and Internet in % of monthly GNI per capita (ITU)
  - **Uptake of connectivity**: Unique mobile telephony and Internet subscribers in % of population (GSMA)
  - **Digital inclusion**: % of women with a mobile Internet subscription; and % of rural residents with a mobile Internet subscription (Gallup Survey)

Methodology

- Data on 137 developing countries (2008 – 2020)

- Treatment variable
  - A **tower acquisition transaction** involving the transfer of towers from a mobile network operators to an independent tower company (TowerXchange)
  - Mergers between tower companies and bilateral infrastructure sharing are not taken into consideration but are rare
  - Tower transactions involve various sizes. Different thresholds of transaction size have been considered in defining a binary treatment variable

Methodology

- DiD with different timing of treatment (Callaway Sant Anna, 2021)
- Key estimate: Average treatment effect of the treated (ATT)

$$ATT(g,t) = \mathbb{E}\left[\left(\frac{G_g}{E[G_g]} - \frac{\frac{\hat{p}(X)C}{1-\hat{p}(X)}}{E\left[\frac{\hat{p}(X)C}{1-(\hat{p})(X)}\right]}\right)(Y_t - Y_{g-1})\right]$$

Results

- **Availability of mobile Internet**

Table: Estimates of average treatment effects on internet coverage.

group	ATE	std. error	p. value
Coverage 3G	0.032	0.020	0.110
Next year coverage 3G	0.042	0.015	0.006
Two years after coverage 3G	0.085	0.025	<0.001
Coverage 4G	0.078	0.040	0.049
Next year coverage 4G	0.096	0.031	0.002
Two years after coverage 4G	0.078	0.042	0.066

Results

- Digital inclusion

Table: Estimates of average treatment effects on digital inclusion

group	ATE	std. error	p. value
Rural households	0.041	0.017	0.013
Next year rural households	0.020	0.018	0.279
Two years after rural households	0.025	0.022	0.259
Woman households	0.052	0.023	0.024
Next year woman households	0.030	0.019	0.121
Two years after woman households	0.023	0.017	0.175

Concluding remarks

Main findings

- The welfare-maximizing number of mobile telecoms operators is 4.

- Even in a market with 3 MNOs (almost symmetric), the NSA between 2 operators is enhancing the consumer welfare

- Shared telecom infrastructure does
  - does increase access to connectivity by increasing availability and improving affordability
  - does also supports digital inclusion by increasing access to connectivity for women and people living in rural areas.

Policy implications

- Regulatory authorities should encourage NSAs among telecom operators for the deployment of mobile telecoms technologies
- In developing countries, shared infrastructure is a viable option to enable universal access to quality connectivity

Thank you for your attention!