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Conference Paper

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30th European Conference of the International Telecommunications Society (ITS): "Towards a Connected and Automated Society", Helsinki, Finland, 16th-19th June, 2019

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Basaure, A.; Finley, B. (2019) : Urban 5G regulation: local licensing versus coopetition, 30th European Conference of the International Telecommunications Society (ITS): "Towards a Connected and Automated Society", Helsinki, Finland, 16th-19th June, 2019, International Telecommunications Society (ITS), Calgary

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Urban 5G regulation: local licensing versus coopetition

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Abstract

Deployment of 5G networks is often described as a disruptive phenomena. Specifically 5G should enable new emerging Internet of Things (IoT) applications. However, such applications require new regulation and business models to incentivize costly infrastructure investments. Currently, no clear consensus exists on the appropriate regulatory regime for 5G urban deployment.

This work explores two alternative regulatory scenarios for a connected vehicles scenario to analyze how the most important regulatory decisions affect an urban network deployment. One alternative is to maintain the current scheme of spectrum assignment while facilitating additional flexibility for infrastructure sharing (ex-post competition). The other alternative is to define local areas for monopoly 5G provisioning and define the conditions for competition ex-ante.

Through agent-based simulations, this work shows that a local licensing scenario may achieve a better performance than a coopetition scenario. Additional sensitivity checks also help detail the existing trade-offs. Finally, the work discusses the implications and limitation of the findings.

Keywords: 5G; IoT; connected cars; regulation; local licensing; coopetition; ex-ante versus ex-post competition

1. Introduction

5G networks require a high-density deployment to achieve high capacity and low latency Internet access for new emerging Internet of Things (IoT) applications. This requirement creates the need for new regulatory schemes enabling flexible business models for mobile network operators (MNOs). In fact, incumbent and new entrant MNOs will not invest in expensive 5G coverage without a new mechanism allowing them to monetize such investments [1]. Connected vehicles have arisen as one of the most promising IoT use cases, since such vehicles may impact not only the vehicle industry but the whole society [2]. However, such service adoption suffers from high uncertainty, and therefore MNOs are demanding new co-investment and risk sharing schemes for a timely deployment of 5G networks [3].

From a general perspective, IoT services such as connected vehicles consist of several technical and business layers. In the infrastructure layer, MNOs provide connectivity in different geographical areas (e.g. cities, neighborhoods) to mobile devices (e.g. vehicles) which require network access throughout their journey. A network broker (regulated entity acting as a middle layer) coordinates the access of users to different network infrastructure, and service providers or tenants (upper layer) manage the relationship with the final customer and manages an IoT data platform. Service providers may be similar to current mobile virtual network operators (MVNOs). MNOs may also act as a service provider by managing the link with the customer and holding an IoT data platform.

The above mentioned interaction between layers and roles requires further flexibility to incentivize network investment. From this perspective, the regulation of new IoT infrastructure and related spectrum policy has emerged as a topic of concern.

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This work aims to analyze different spectrum regimes and related regulatory and business requirements which impact investment incentives and the overall economic efficiency of the market. With this purpose, the work utilizes agent based modeling simulations to identify which regulatory regime is most suitable for an IoT connected vehicle use case and in more general terms inform the regulatory conditions for a successful 5G urban deployment.

2. Background

With the advent of 5G, the telecom industry is preparing the deployment of new emergent IoT applications which may differ from the traditional mobile Internet traffic generated by humans. In fact, many IoT applications (such as connected vehicles or more generally smart city applications) require a high density network deployment, which cannot be achieved by the traditional oligopolistic competition and related regulatory framework.

From a technical perspective, the demand for high capacity and low latency mobile Internet access can be addressed by edge computing and network slicing solutions [4, 5]; however, the incentives for deploying such solutions are still unclear. Other challenges include interference management, spectrum allocation, and handover management [6].

Generally, higher uncertainty exists in terms of service adoption and investment incentives. For example, fully automated vehicles requires cultural changes in society, and these changes have been identified as slow moving [7]. This may prevent some services achieving critical mass. For a connected vehicle scenario, there are several use cases which can be classified, for example, into vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P) and finally vehicle-to-everything (V2X). The real value of each use case is still an open question, while the technical requirements are diverse [4, 8].

In terms of the regulatory framework, [1] identifies different alternatives for a 5G network rollout. One alternative provides mobile network operators (MNOs) stronger incentives to invest in infrastructure by not regulating access prices. Another alternative emphasizes a public role (i.e. city or government) in deploying urban networks and letting operators to compete in the service provisioning as mobile virtual network operators (MVNOs). Additionally, [1] argues that a *status quo* alternative (oligopolistic competition) will at least need some changes by including, e.g., infrastructure and spectrum sharing.

Overall 5G deployment scenarios change the current paradigm and require high risk investments. Therefore in 2016, MNOs stated in their 5G manifesto the need for fewer and simpler regulatory rules, including withdrawal of ex-ante regulation (i.e. access pricing), investment incentives via risk-sharing models, and in case of access pricing remains, long-term commercial agreements should be encouraged.

New technology developments related to network slicing and network function virtualization enable new business models [9]. These developments separate the network from the service provisioning, therefore allowing multiple mobile operators (i.e. multi-tenants) to access the same 5G network to provide users service. Furthermore, these technologies may utilize different radio access networks (RANs), for example 5G and LTE, to provide virtual connections to users, regardless of the ownership of the network. This idea of multitenancy increases network utilization but may also increase the risk of monopoly power in the network provisioning, even though simultaneously enabling new entrants in the service provisioning.

In this context, a new regulatory framework should incentivize MNOs to realize the high potential of 5G for increasing the value of its service offering [10], while at the same time maintaining a competitive market.

2.1. Spectrum allocation

With the increase of mobile data usage and the evolution cellular networks, the International Telecommunication Union (ITU) has been working for allocating more spectrum for mobile Internet. The 3.5 GHz, which was prepared for mobile usage already by the World Radio Conference (WRC) in 2007, and the 700MHz have been recently assigned for 5G in several countries. Besides sub 6GHz bands, those frequencies above 24GHz, or so-called millimetre waves, have been considered for 5G. While waiting for the WRC 2019 to define further spectrum for 5G, the frequency bands between 3.4 and 4.2 GHz have been under active study in Europe [11] and US [12, 13].

Spectrum is typically assigned in a nation or statewide basis. In recent years, many studies have argued on the convenience of spectrum sharing [14] and in assigning locally spectrum for incentivizing a more flexible reuse [15].

5G dense urban network deployments face many technical challenges, such as interference management, handover requirements and backhaul loading balance [16]. On the economic side, a 5G deployment has characteristics of natural monopoly, since it requires a high density network and there is no enough demand for maintaining 3 parallel mobile networks providing high capacity in specific areas. While network virtualization and network slicing technologies enable new business models by logically separating the provisioning of network access from the service, they do not incentivize facility-based competition and therefore they do not incentivize infrastructure investment [17]. For example, some authors such as [18] argue that in the fixed Internet case facility-based competition with government support facilitated early adoption of services and resulted in better outcomes than imposing network access unbundling (or infrastructure sharing).

An analogy may be found from the energy market, where transmission network is separated from energy production. In energy markets there are two types of tradable transmission rights which may be allocated through an auction or other mechanism. Physical transmission rights (PTR) gives the holder exclusive right to transport a predefined quantity of power between two locations on the network. PTRs encounter many limitations such as inflexibility in rights trading and the possibility that a PTR holder keeps its rights unused to artificially maintain transmission prices high. On the other hand, Financial transmission rights (FTR) gives the holder the right to receive payments equal to the energy price between the source location to the destination, paying the holder congestion rents. Thus, FTRs create an open access to the transmission system for any participant, regardless who holds the right. In addition, FTRs create incentives for investing in capacity, because market participants pay for congestion. They receive FTRs in exchange for building capacity and it is cheaper to build capacity than paying for congestion [19].

Even though a 5G urban deployment highly differ from energy networks, these problems resemble as both are a natural monopoly. In fact, both need a mechanism to open the network to several service providers and to define incentives for incentivizing investing in infrastructure over time.

This paper studies the effect of spectrum regime on system performance and overall economic efficiency by comparing two alternative ways of assigning spectrum. The first way is to allocate as usual, by dividing the available spectrum into e.g. three spectrum bands and auction them for existing or new MNOs. An alternative way is to assign such spectrum in a local basis, e.g., by city or municipality, so that one local operator manages the network in each licensed area.

The scenarios to be analyzed are described as follows:

1. Coopetition. Spectrum is allocated as usual (one spectrum band per network operator). Each operator competes based on infrastructure, but infrastructure sharing (spectrum and base stations) is allowed in low-density areas. Infrastructure sharing has been widely suggested for 5G implementation [20]; however, full infrastructure sharing creates monopoly power. This scenario aims at combining the advantages of sharing for those areas efficiently with low density of users, with the advantages of infrastructure competition for those with high density of users.
2. Local licensing. Available spectrum is allocated to operators (incumbent or new entrants) locally per zone. One operator provides network access to all service providers within one geographical area (this is an extension of the concept of local licensing, such as described by [15]). Access prices are defined in the license conditions via a market-based mechanism (ex-ante price competition). This scenario aims at achieving technology efficiency by reusing the same radio spectrum locally. On the other side, it may create some interference in the border between areas. In addition, access pricing regulation is a poor substitute for a competition regime. And finally, local licensing does not incentivize infrastructure-based competition.

These scenarios compare ex-ante with ex-post competition. In addition, both scenarios includes a relation between cooperation and competition. In a coopetition scenario, 5G MNOs compete ex-post in high density areas while cooperate in low density areas. In a local licensing scenario, 5G MNOs compete ex-ante to provide local connectivity, and cooperate by providing access to all users to their network.

2.2. Competition models

It is widely acknowledged that MNOs can compete in prices or in quantity. MNOs compete *a la Cournot* when building capacity and *a la Bertrand* when they compete in acquiring customers [21]. Traditional view states that competition under Bertrand (price) is more intense than under Cournot (quantity); however, the superiority of Bertrand may be limited under several circumstances. For example, under strong R&D spill-over and low differentiation of products [22]. Furthermore, Bertrand advantage may not hold under uncertainty, and firms may charge higher prices [23]. In a two stages game, when quantity is pre-committed during the first stage, a price-Bertrand competition will end up in a Cournot equilibrium, where, the equilibrium will equal the Cournot outcome [24]. The same is true for differentiated products [25].

In the economic literature, the right to be a local monopoly provider is awarded via a franchise bidding to the lowest cost bidder, subject to meeting predefined quality requirements. This mechanism was originally proposed by Demsetz in 1968 [26] and it can be thought as contrary to paying the highest fee through an auction allowing free retail prices (i.e. traditional spectrum auction). By allocating a licence according to a bidding mechanism, it induces monopolists to behave as they were in competition. However, the franchise bidding has been criticized as it may enable opportunistic behaviour or winner curse, when technology, demand or costs radically change over time. To address these problems, the licensing conditions should include a mechanism to change the price according to cost and demand volatility. Typically under uncertainty it is not possible to make complete contracts in a long term. A well known historical case was a franchise bidding organized in the US for cable television (CATV), where most of the agreements were renegotiated. In short, competition was introduced but regulatory burden remained high [27].

3. Method

3.1. Agent based modeling

Agent based modeling and simulation is a general purpose method that performs a bottom-up analysis of complex adaptive systems, which emphasizes the adaption and interaction of individual agents following a simple set of rules. In contrast to strict equation based modeling, agents are autonomous and behave according to decision rules within an environment constraining them and the model itself is not usually analytically tractable. Agent based modeling and simulation is especially useful for analyzing complex systems since such analysis is able to illustrate macro level emergent phenomena from micro level agent behaviors [28] [29]. Agent based modeling naturally fits well with the analyzed problem, since mobile networks and interacting autonomous users can be seen as a complex system. Several general agent based modeling platforms are open source and freely available including for example MASON¹ and FLAME.² This work utilizes the Repast Simphony³ framework because the framework supports development in Java and the Java ecosystem provides a large variety of useful third party math and statistics libraries. In terms of implementation, the model contains about 2560 lines of Java code.

3.2. Overall model parameters

The agent based model performed herein includes several general parameters affecting the behavior of all existing sub-models and agents throughout the simulation. Firstly, time progresses in the model discretely with a one second granularity, and thus decisions are made by all agents and the entire model is updated and progresses every one second. This time granularity provides an adequate level of network detail and realism while still providing feasibility in terms of execution time.

As mentioned the model can be further broken down into sub-parts such as the vehicular mobility and the network model. These sub-parts are described in detail in sections 3.3-3.5. Scenario specific model differences are noted when applicable.

¹<http://cs.gmu.edu/~eclab/projects/mason/>

²<http://flame.ac.uk/>

³<http://repast.github.io>

3.3. Simulation area and street layout

The simulation area is an 800x800 meter square with wrap-around boundaries and an overlaid street network. The street network is a Manhattan style grid of larger vertical streets (i.e. thoroughfares) and smaller horizontal streets. The inter-street distances for vertical streets and horizontal streets are 250 and 100 meters respectively. Each street has light poles with a staggered layout and a specific inter-pole distance. Each light pole has at least one (and more in the co-location scenario) 5G base station near the top of the pole (assuming height of approximately 8 meters, below rooftop).

3.4. Vehicular mobility model

The vehicular mobility model is essentially a weighted random walk with vehicles limited to traveling on the street network. In detail, each vehicle travels with a constant speed selected at model start up from a truncated normal distribution, $N(36, 9, 18, 63)$ km/h. At 20 meters before an intersection, the vehicle slows down by a factor of 75% to simulate higher congestion at intersections. At the intersection itself, the vehicle chooses to turn or continue straight with weighted probabilities such that the larger vertical streets are preferred. Specifically, if a vehicle is already on a vertical street the probability of continuing straight is 80%, while if a vehicle is on a horizontal street the probability of turning (onto a vertical street) is also 80%. In other words, there is a steady state of 80% of vehicles on vertical streets and 20% on horizontal streets. As mentioned the simulation area wraps around so vehicles that move beyond a simulation border continue on the opposite side.

For simplicity purposes the vehicles do not interact with each other or cause traffic congestion as such but instead such congestion is approximated through the aforementioned slowing at intersections and additionally simulated traffic jams. The simulated traffic jam mechanism is simply a defined rectangular area where the speed of all vehicles within is decreased by a specified constant factor.

3.5. Network model

The network model is essentially a high level system model of a 5G radio access network. Thus it only models base stations and considers backhaul and core network as out of scope.

The network model calculates the signal strength, bandwidth, and corresponding throughput available to a given agent based on the proximity of that agent to a BS(s), the number of users using that BS(s), and the radio resource allocation scheme. The model makes several simplifying assumptions including that BSs operate at constant power all the time (thus it does not consider power optimization) and that fast fading smooths out at one second time scale (and thus it can be ignored). Table 1 details a variety of other network simulation parameters.

Table 1: Various network model parameters.

Parameter	Value
BS transmission frequency (center)	3.5GHz, 24GHz
BS transmission power	21 dBm
Antenna gain	2.1 dB
Path loss model	ITU-R P.1411-9, urban outdoor environment
Reusage factor	5
Noise power	0.32nW
Handover penalty (interoperator)	1s
Handover penalty (intraoperator)	$\sim N(40 \text{ ms}, 22 \text{ ms}, 10 \text{ ms}, 100 \text{ ms})$
BS separation	150m (horizontal), 50m (vertical)
Vehicle density	$470/\text{km}^2$
Vehicle speed	$\sim N(36 \text{ km/h}, 9 \text{ km/h})$

In order to calculate the signal strength the network model utilizes different empirical path loss models, which takes into account both the LOS and NLOS contexts, depending on whether the user and base station

have a line of sight. The network model assumes that vehicles have LOS with all BSs on their current street and with both current streets when in an intersection. Specifically, the model uses the ITU-R P.1411-9 [30] site general model for propagation within street canyons below rooftop as detailed in the following equation:

$$L(d, f) = 10 * \alpha * \log_{10}(d) + \beta + 10 * \gamma * \log_{10}(f) + N(0, \delta)$$

where d is the direct distance between the transmitting and receiving stations (m), f is the operating frequency (GHz), α is the coefficient associated with the increase of the path loss with distance, β is the coefficient associated with the offset value of the path loss, γ is the coefficient associated with the increase of the path loss with frequency, and $N(0, \delta)$ is a zero mean Gaussian random variable with a standard deviation δ (dB). Table 2 summarizes path loss parameters for LOS and NLOS cases.

Table 2: Path loss model parameters.

Parameter	LOS	NLOS
α	2.12	4
β	29.2	10.2
γ	2.11	2.36
δ	5.06	7.6

The model also differentiates between two types of BSs: shared BSs and exclusive BSs. The shared BS serves all users within a coverage area using the entire available spectrum band due to a local monopoly (local licensing case) or a shared infrastructure (coopetition case). In contrast, an exclusive BS serves only own operator users using the operators assigned fraction of the spectrum band (infrastructure competition in the coopetition case).

In terms of interference, the model considers both intra-operator and inter-operator interference, following a time division duplex (TDD) scheme. Inter-operator interference assumes high coordination and it is calculated based on a dynamic BS grouping scheme. Specifically only a single BS in each BS group (except for the serving BS's group) interferes with the serving BS. Therefore, this coordination allows for a reduction in the number of interfering BSs by the group size N . The BS groups are dynamically derived for each vehicle at a given location such that the closest N BSs form one group, the next closest N BSs form another group, and so on. In the inter-operator case, BSs belonging to different operators are not able to coordinate. The interfering BS from each group is chosen randomly to represent an average case interference. The interference calculation also takes into account the different spectrum allocations (spectrum band exclusively allocated to one operator or equally divided between operators).

All path loss models give a signal to interference plus noise ratio (SINR). This SINR along with the user bandwidth are then transformed to a throughput value via an approximate bounded and truncated Shannon function. The function (as dictated by appropriate adaptive coding and modulation schemes) is provided by 3GPP in Section A.2 of [31].

3.5.1. Resource allocation scheme

The network model performs a frequency domain resource scheduling (FD-RS) by allocating the bandwidth of each BS between the active users in each iteration. This implies a time domain equal resource allocation since all active users are scheduled each second. The model includes two simple and intuitive FD-RS schemes.

An equal resource (ER) allocation scheme (utilized as a base case in this work) divides a BSs bandwidth between all users regardless the channel quality (SINR). This scheme is essentially channel unaware and it has been utilized in commercial networks [32]. A throughput equalization scheme (TE) is channel aware alternative which allocates BSs bandwidth between all users inversely proportionally to each channel capacity (calculated from the SINR). Both schemes try to implement some level of fairness between users but with different criteria (bandwidth vs. throughput). Additionally, the ER scheme is fair at the level of each individual BS ([33]).

3.5.2. BS selection scheme

Each user selects every second the BS with the best estimated throughput given the decisions of all other users. Therefore, the first user to select a BS has no information about other users, while the last user obtain complete information. To avoid any unfairness, the model randomizes the order of the selection process every iteration (e.i. second). Furthermore, users possess complete information when making their BS selection, since their throughput estimation considers both the BSs already selected by others and the radio resource allocation scheme. For further information about this BS selection scheme, see Section 3.3.2 of [33].

4. Scenarios

4.1. Simulation procedure

The simulation procedure is as follows. Each run simulates (via the agent based model) 36000 seconds (6 hours) of user action as this duration allows a good convergence of the simulation results. Figure 1 illustrates a high level flow diagram of this simulation process. Each simulation was performed on a standard computer with Intel Core i7 (2.5 Ghz) and 16 GB RAM and took between 15 and 45 minutes time depending on the number of agents in the scenario and other conditions (e.g., congestion).

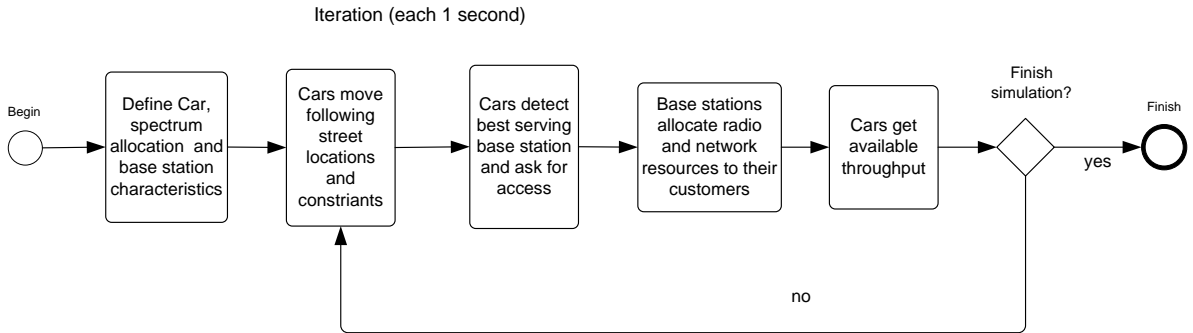


Figure 1: High level simulation flow chart.

4.2. Local licensing scenario

Figure 2 (left) depicts the implementation for simulating a local licensing scenario. Each operator holds areas of high traffic density (vertical streets) and low traffic density representing different areas of a city. The boundary between areas are located in areas of low traffic (horizontal streets) which may exemplify a common administrative division of big urban areas. Since the simulation area wraps around, each mobile operator borders the other two in a symmetrical fashion.

4.3. Coopetition scenario

Figure 2 (right) depicts the implementation for simulating a coopetition scenario. In high density vertical streets, MNOs perform an infrastructure competition by locating their BSs in different light poles. In this case, users are served by BSs belonging to own operator and there is no any cooperative mechanism such as spectrum sharing. In low density horizontal streets, MNOs perform infrastructure sharing by allowing one operator per area to maintain the whole infrastructure and allow all users to access that infrastructure. When the infrastructure is shared, the corresponding operator can transmit in all available frequency bands.

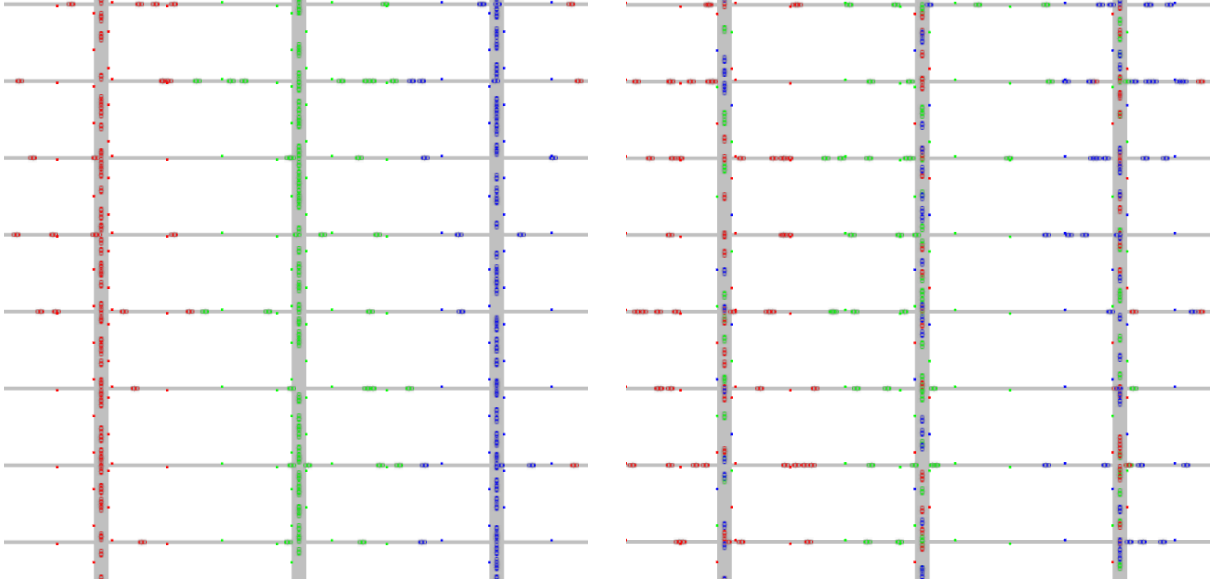


Figure 2: Simulation implementation for (left) local licensing and (right) coopetition scenarios.

This scenario also includes a case, where BSs are colocated in the same light poles (i.e. passive infrastructure sharing) in areas where MNOs are competing in infrastructure.

Table 3 summarizes the main differences of the two scenarios to be compared.

Table 3: Main assumptions of scenarios.

Parameter	Local Licensing	Coopetition
Frequency	each operator transmits in all spectrum band	operator transmits in all spectrum band on horizontal streets and in own spectrum band on vertical streets
Interference	not coordinated between areas	not coordinated between operators regardless of area
Type of Competition	ex-ante	ex-post

4.4. Parameter variations

Besides spectrum regimes, as defined in previous scenarios, the simulation varies several parameters to perform a wider sensitivity analysis of the results.

Density of BSs: The model includes the possibility of changing BS density in both horizontal and vertical streets

Radio resource allocation scheme: The model include a channel aware TE radio resource allocation scheme and a channel unaware ER scheme.

Number of vehicles: The model can vary the number of vehicles thus creating different vehicle density levels.

Traffic jams: The model can vary the traffic behavior in certain areas to simulate the effect of traffic jams on the system performance.

Number of MNOs: The model can vary the number of MNOs thus testing other regimes such as monopoly.

Frequency bands: The path loss model accept a wide range of frequencies thus enabling the comparison of different possible frequency allocation for 5G urban deployments.

BS grouping: The model can group BSs by different size thus testing how different reuse factor affect the performance if the urban network.

4.5. Results

The following section presents the simulation results by showing the signal strength in terms of signal to interference and noise ratio (SINR) in dB and its corresponding throughput in Mbps for different scenarios (i.e. spectrum regimes) and cases (i.e. parameters variations). Results are shown as cumulative distribution functions (CDFs).

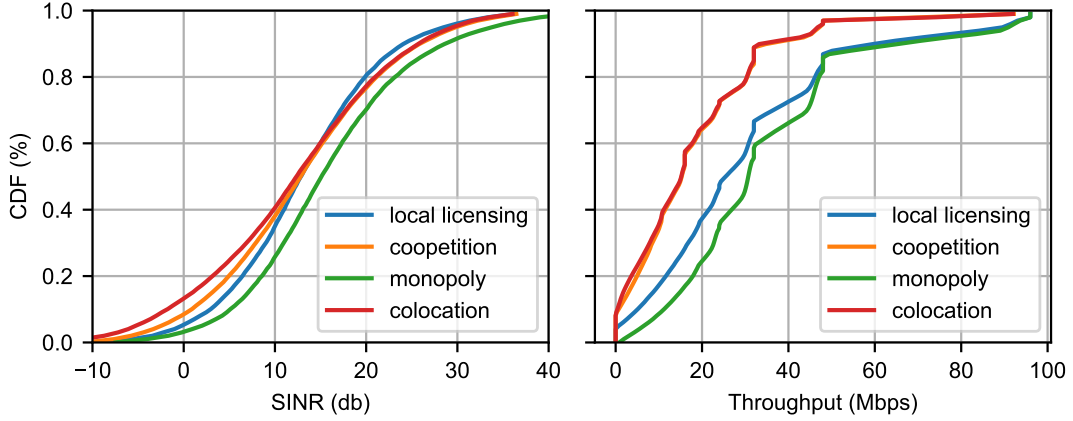


Figure 3: Results for baseline case: CDFs of SINRs and throughputs for different scenarios including local licensing (LL), cooperation (CP), monopoly (MON), and collocation (COLO).

Figure 3 shows the baseline results by comparing the CDFs of SINR and throughput for different spectrum regimes. When comparing local licensing and cooperation scenarios, local licensing shows higher performance in terms of throughput and similar performance in terms of SINR. This implies that local licensing achieves a higher utilization of spectrum. In addition, the technical efficiency of the monopoly scenario is slightly better than a local licensing scenario. This difference is primarily due to the performance penalty of inter-operator handovers. Finally, in the collocation case, which depicts a variation of the cooperation scenario in which BSs are collocated in vertical street poles for infrastructure competition, shows very little difference with the cooperation scenario.

Figures 4 and 5 illustrate the urban network performance under different traffic patterns. First, in Figure 4 a traffic jam of 400x400 meters in which vehicles move at 25% of the original speed is placed in the middle of the simulation area. Secondly, in Figure 5 the total number of vehicles in the simulation area is varied between 100 and 900. Both Figures shows similar patterns and suggest that these varying traffic patterns effect the magnitude of the underlying difference between the local licensing and cooperation scenarios. In particular, Figure 4 illustrates that local licensing has a larger relative advantage without the traffic jam, and similarly Figure 5 shows that local licensing has larger advantage in low traffic (e.g. 100 vehicles). While under congestion, the scenarios more closely resemble each other. In other words, with low congestion local licensing shows a higher level of flexibility in utilizing spectrum.

The next sensitivity analysis adjusts the BS density by varying the BS separation distance in horizontal and vertical streets. In the baseline scenario, BSs are located every 50m in vertical streets and every 150m in horizontal streets, roughly in line with vehicle traffic distribution (80%/20%). Figure 6 varies the baseline separation between 50m and 300m for horizontal streets and from 15m to 100m for vertical ones. This is equivalent in changing the BS density (and infrastructure investment) to 50%, 200% and 300% of its original value. The results show that for local licensing a 50% BS density significantly diminishes

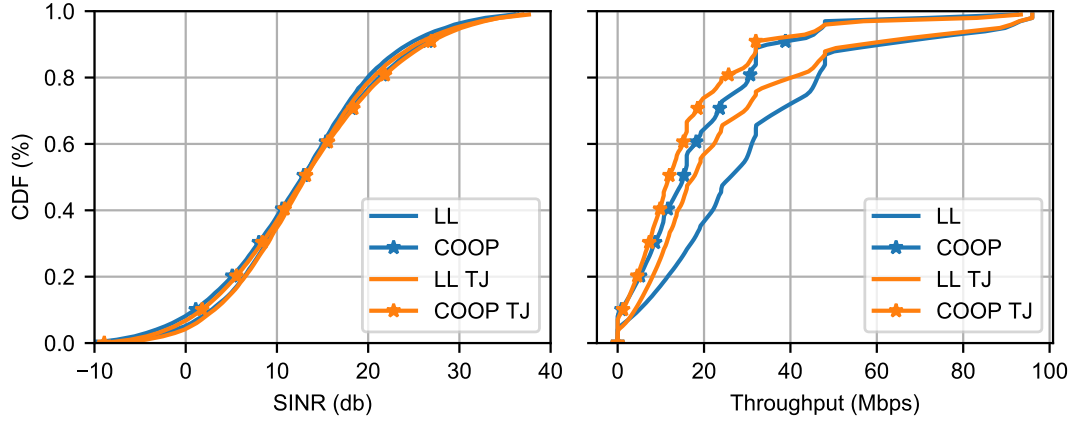


Figure 4: Results for traffic jam (TJ) case: CDFs of SINRs and throughputs for different scenarios including local licensing (LL) and cooperation (CP).

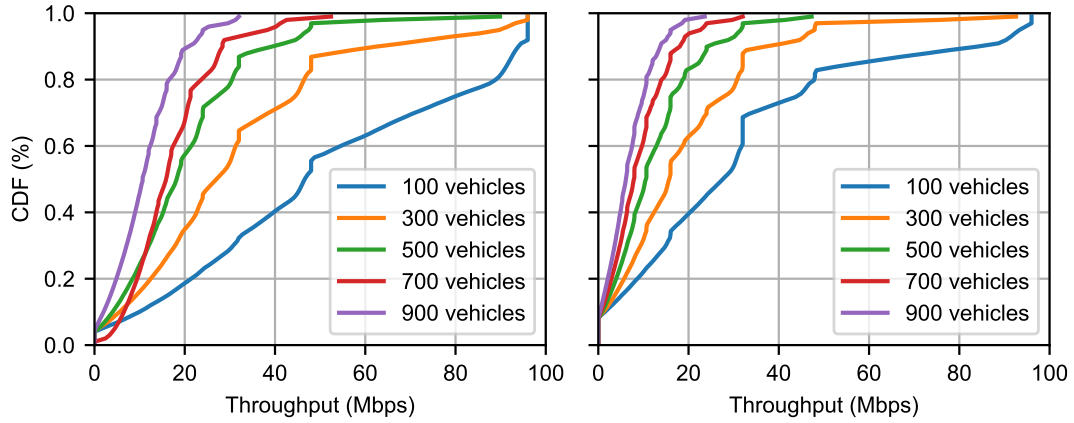


Figure 5: Results for vehicle density case: CDFs of throughputs for different scenarios including local licensing (left) and cooperation (right).

throughput whereas a 200% BS density does not proportionally increase throughput. In other words, the results illustrate diminishing returns on densification. The cooperation scenario does not suffer from the same level of diminishing returns because of its initial lower level of efficiency. Specifically, a 200% BS density provides a comparable absolute change in throughput to a 50% BS density. In other words, there is a critical point after which increasing BS density does not significantly increase throughput, and local licensing achieves this point with fewer BSs. Note that an increase in interference from BS densification is not driving these results as Figure 7 illustrates.

Figures 8 and 9 perform a sensitivity analysis with some technical parameters such as transmission frequency and scheduling algorithm. Figure 8 shows that changing from 3.5GHz to 24 GHz has very little effect on network performance for an outdoor urban deployment with high density of BSs. Note that the amount of allocated spectrum remains the same and the model does not consider that in practice more spectrum is available in higher frequency bands. Additionally, Figure 9 illustrates that the advantage of local licensing against a cooperation regime remains unchanged for different scheduling algorithm (BET scheme equalizing throughput versus ER equalizing spectrum resources). Note that a better performance of ER against BER is a well known issue already studied for example in [33].

Finally, Figure 10 varies the frequency reuse factor by grouping the BSs with different sizes. The baseline utilizes groups of 5 BSs and this analysis includes groups of 7 and 3. As a result, Figure 10 shows that the smaller the group, the better the throughput of the network. However, this assumes a static

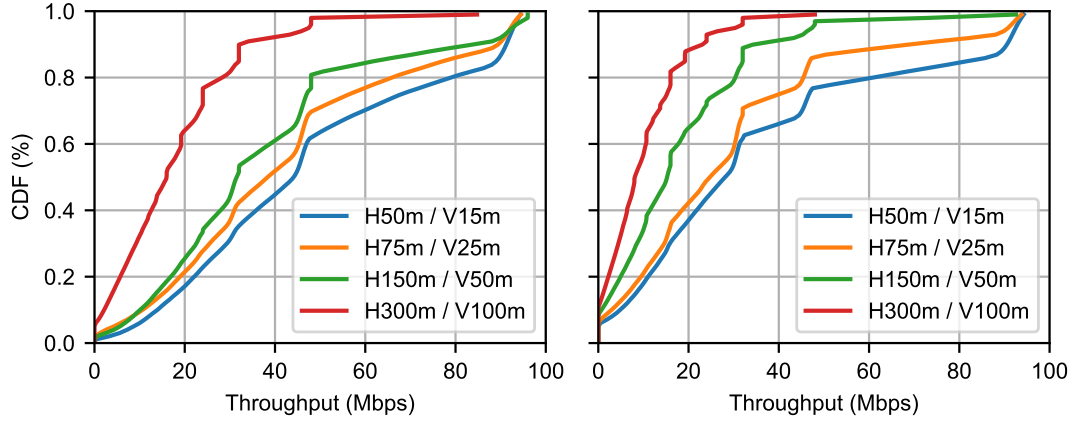


Figure 6: Results for BS density case: CDFs of throughputs for different scenarios including local licensing (left) and cooperation (right).

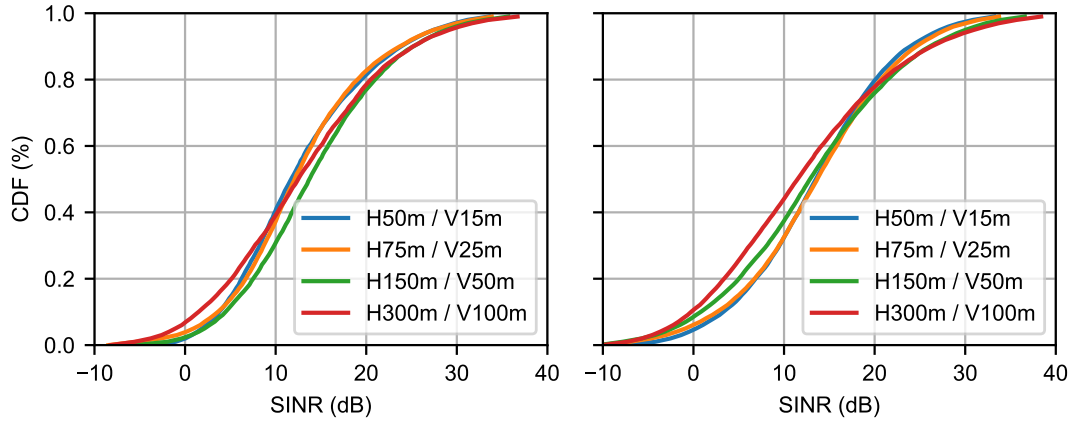


Figure 7: Results for BS density case: CDFs of SINR for different scenarios including local licensing (left) and cooperation (right).

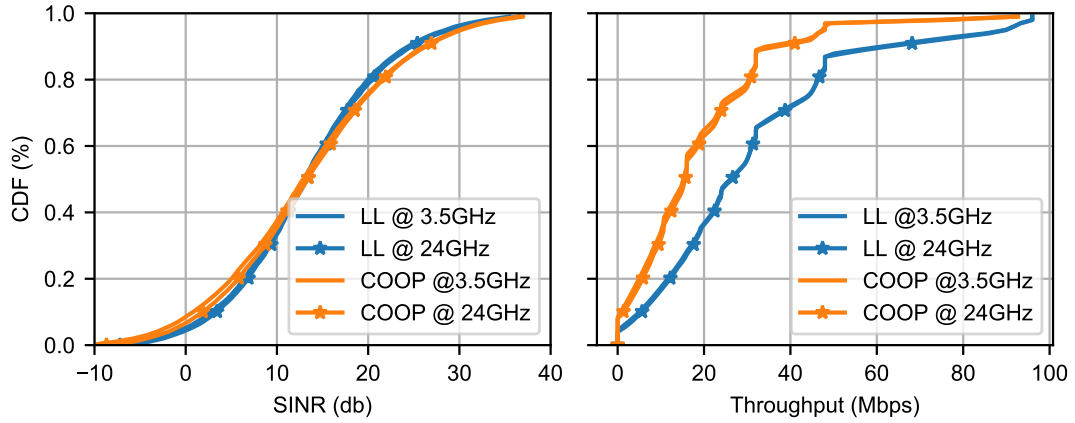


Figure 8: Results for frequency band case: CDFs of SINRs and throughputs for different scenarios including local licensing (LL) and cooperation (CP).

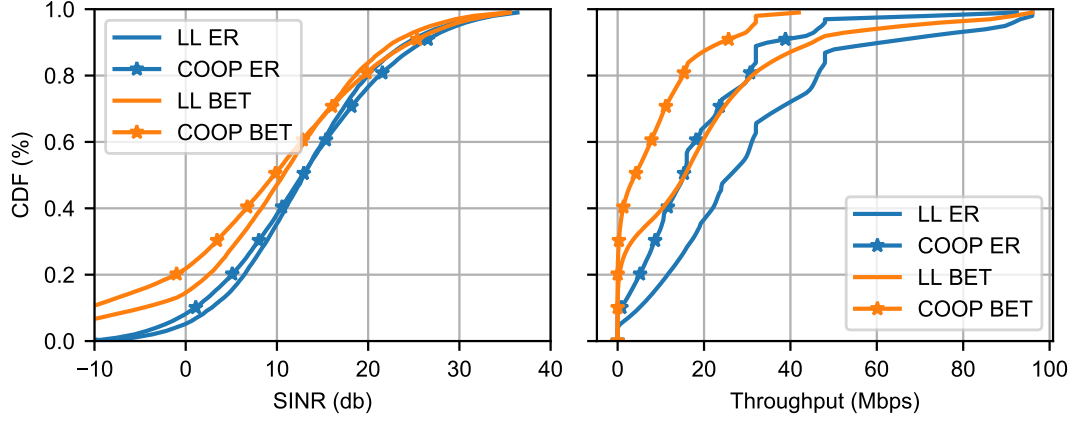


Figure 9: Results for BS scheduling case: CDFs of SINRs and throughputs for different scenarios including local licensing (LL) and cooperation (CP).

spectrum allocation per BS and cannot be generalized for all cases. More importantly, Figure 11 shows that local licensing maintains an advantage with different group sizes, even for the extreme case of group size of one.

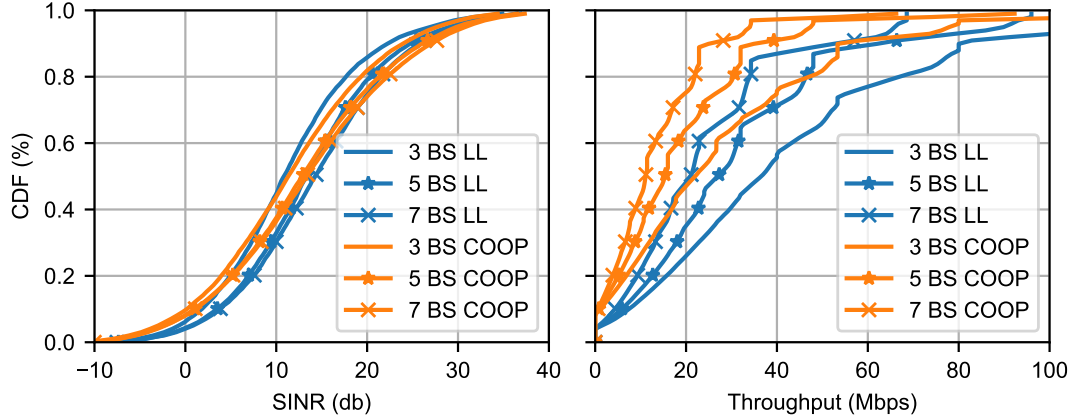


Figure 10: Results for BS group size case: CDFs of SINRs and throughputs for different scenarios including local licensing (LL) and cooperation (CP).

4.6. Effects of network assumptions on results

This section briefly discusses the potential impact of several of the network assumptions on the results. Since the model analyses the access network as a bottleneck and does not include backhaul or core network. Therefore, these results may be less accurate for scenarios where the limiting bottleneck is in the backhaul or in the core network, however, they are still applicable. In fact, the model is not analyzing the effect of network congestion on latency. Even though connected cars may demand low latency applications, it is not yet clear how demanding these requirements are and therefore this work prefers to provide the analysis utilizing throughput. To describe those bottleneck present in other areas of the network, the BS selection would need to consider end-to-end load and not only BS load (such as performed in [34]). In any case, the bottleneck is more likely to be in the radio access network in the analyzed scenarios than in backhaul or core network. For example, many urban areas often have expandable high capacity fiber-to-the-BS backhaul.

Secondly, the model makes certain radio access network assumptions such as constant transmission power of BSs and static spectrum allocation for each cell according to a predefined re-usage factor. These

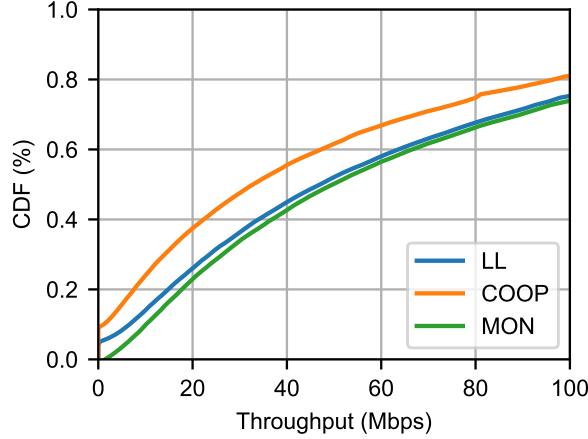


Figure 11: Results for BS group size one case: CDFs of throughputs for different scenarios including local licensing (LL), coopetition (CP), and monopoly (MON).

assumptions spectrally constrain the system and therefore the results likely underestimate the throughput of high re-usage factor schemes compared to, for example, soft or fractional frequency reuse [35]. However, these issues do not impact the direction of the results as all agents are equally affected since they move extensively over the simulation area. Additionally, even highly detailed tools, such as the LTE system level Vienna simulator, [36] do not yet support non-homogeneous power allocation.

Finally, the simulations do not consider the interaction between LTE and 5G networks. From this perspective, MNOs having 4G networks have an advantage as compared with those without them. However, the intention of these simulation is to compare the performance of 5G urban network alone under different spectrum regime scenarios.

5. Discussion

The simulation results show that a local licensing regime achieves a better performance than a coopetition regime in all analyzed cases. This is mainly because of the better spectrum usage achieved in a local licensing scenario rather than more optimized interference management. In other words, efforts to increase spectrum usage will result in a better outcomes regardless of the possible increase in interference. This observation is intuitive since the generated interference in high frequency bands is relatively low as compared with the possible gains achieved by utilizing spectrum more efficiently. In line with the previous consideration, a local licensing regimes performs only slightly worse than a monopoly.

As observed from the sensitivity analysis, the magnitude of the differences will depend on many variables such as traffic patterns, antenna planning and design, antenna density, frequency and scheduling configuration, etc. Furthermore, the magnitude of the differences will likely depend on street shape and the administrative division of each city. However, the simulation setup is intended to represent a general urban area to address most the important trade-offs such as interference and spectrum utilization and therefore these results are can be extrapolated to many cities.

The simulation does not include a rigorous comparison between local licensing and coopetition regimes in terms of competition dynamics and price uncertainties. The simulation results only illustrate that local licensing has better performance because it better utilizes spectrum resources. The overall competitive outcome should be analyzed in a case by case basis. Local licensing needs a flexible pricing scheme which considers the uncertainty and volatility of service demand. Under very high uncertainty, a coopetition regime may still have advantages since it does not require MNOs to fix a price scheme significant periods of time. However, in practice, local licensing may include a renegotiation clause which also diminishes such risk. Note that in any case the high uncertainty present in new IoT applications require from the regulatory authorities a more active role in incentivizing investments, regardless of the chosen regulatory regime.

Network slicing and virtualization is another technology of interest that could enable 5G urban infrastructure to compete against 4G and 5G macrocells by commoditizing different radio network technologies. This potential depends critically on the latency requirements of emerging IoT services which are not addressed in this work. In this case, any chosen regulatory regime will not require as much regulator involvement to assure a successful deployment.

6. Conclusions

This work illustrates that traditional spectrum allocation (which incentivizes oligopolistic infrastructure competition) has lower performance than an alternative local licensing regime in a 5G urban deployment. This is true even in a case where infrastructure sharing is allowed (i.e. cooptition regime). However, while a local monopoly may be efficient for a small city, having a single operator control the network of a large city is likely unwise, since such a market structure may damage competition. Specifically, a monopolistic network operator holding macro cellular networks may obtain a dominant position in the market and thus harm competition. An alternative local licensing scheme may achieve technical efficiency while at the same time enabling several MNOs (incumbents and new entrants) to compete in the market. In addition, local licensing may achieve a competitive outcome via ex-ante competition (i.e. license bidding) and thus it may be more convenient than a regulated monopoly (i.e. neutral host), even though a regulated monopoly may achieve higher level of coordination. Local licensing also has some challenges in implementation, and service demand uncertainty may force license renegotiations and thus increase the regulatory burden. On the other hand, an ex-post competition scheme like the cooptition scenario may be more flexible given high price uncertainty but at the expense of spectrum efficiency.

Acknowledgement

The work of Arturo Basaure was supported by the Fondecyt project # 11170100.

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