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## Feasibility of the City-driven Neutral Host Operator: The case of Helsinki

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# Feasibility of the City-driven Neutral Host Operator: The case of Helsinki

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## Abstract

*The large-scale deployment of 5G small cells in an urban environment can be facilitated by allowing the placement of antennas on light poles and by organizing their commercial exploitation via a neutral operator. In this paper, we analyze the feasibility of a city-driven Neutral Host Operator (NHO) for the case of the Helsinki Metropolitan Area by comparing the costs of two alternative small cell deployment strategies. We estimate 5G deployment needs at the postal code level for three future demand scenarios considering different data consumption volumes as well as number of subscriptions for connected devices. For this, we add postal code capacity in a year basis updating existing macrocell sites to 5G and deploying new 5G macro/small cell sites depending on indoor/outdoor demand and offloading. By 2030, about 85%, 90%, and 92% of existing 4G macro sites need to be updated with 5G. Additionally, 34, 816, and 1035 outdoor small cells will be required to serve the three demand growth scenarios, respectively. Although the NHO-driven deployment strategy initially incurs higher costs than the MNO-driven, before 2030 the former accumulates lower costs for all demand scenarios. In case the NHO-driven strategy achieves a 20% cost-savings in public works, this strategy becomes cost-advantageous in 2029 with 728 and 921 deployed small cells for the medium and high growth scenarios, respectively. Cost-saving mechanisms in the NHO-driven strategy should focus on public works since they are the largest contributor to the deployment cost.*

## 1 Introduction

Cities have a growing importance in the digital transformation of societies since they represent the majority of the world's population and global economic activity. The competitiveness of cities depends on the ability of their stakeholders to create new products and services, which can be afterward commercialized worldwide. Since telecommunication infrastructure is a key enabler for these new services, city managers may take an active role, investing in the rollout of 5G small cell networks.

The quality of mobile services has increased in cities through gradual densification and upgrading of base stations (BSs). However, the rollout of 5G small cells requires many more cell sites to provide outdoor download throughputs above 300 Mbps (3GPP, 2018b), which may not be easily available in old city centers, city parks, and highly secured places. To enable a dense city deployment, BSs can be integrated into street furniture, including bus stops, traffic lights, kiosks, or light poles. Light poles are a good cell site since they are ubiquitous in city streets and will remain as a fundamental piece of street infrastructure for the foreseeable future. Hence, they can enable large-scale and hotspot deployment of BS working at 3.5 GHz and 26 GHz, respectively.

The current deployment strategy by Mobile Network Operators (MNOs), which is based on nationwide infrastructure-based competition, may not be feasible in the city context since the cost of deploying overlapping small cell networks might be too high. In fact, there is a common view among MNOs that infrastructure sharing is likely to be a key market aspect for 5G (BEREC, 2018). Since the city is the sole owner of the light poles, city managers may take an active role, partially investing in the transformation of light poles and in the deployment of network equipment. In contrast to MNO

deployments, a light pole-based deployment does not require per-cell negotiation with venue owners and can coincide with the ordinary renewal of light poles. Further, the installation and maintenance of network equipment can potentially be automated as light poles become standardized and produced in volume. In addition, the rollout can be planned with a long-term view<sup>1</sup>, attracting investors.

However, the 5G light pole network needs to rapidly attain minimum utilization levels to become economically sustainable. For this, city managers may create a neutral host operator (NHO), aiming for MNOs to exploit the 3.5 GHz (and potentially 26 GHz bands) via 5G network slicing. Thus, MNOs may offload future outdoor macro-site traffic and serve new use cases, including low-latency services<sup>2</sup>. However, the willingness of MNOs to utilize city-owned neutral infrastructure remains unclear<sup>3</sup>. To understand the feasibility of a city-driven NHO, we study the following research question: *What technical and economic factors would make a city-driven NHO successful?*

We conduct a cost analysis for the deployment of 5G small cells at the postal code level for the Helsinki Metropolitan Area. We compare the cost of two deployment strategies, namely the *MNO-competition-based strategy* and the *NHO-driven strategy*, to identify the traffic levels and cost-saving mechanisms that could induce MNOs to use the light pole-based infrastructure instead of deploying their small cell network. Based on the obtained results, we discuss the feasibility of the city-driven NHO.

The city of Helsinki is an interesting case study since the city has almost 100% 4G coverage<sup>4</sup> with a high mean throughput of 21.4 Mbps (Rewheel, 2019). This high level of coverage along with cheap unlimited data subscriptions have led to very high usage, with a mean monthly usage of 18GB per SIM in H2 2018. Therefore, Helsinki could be one of the first cities in the world, requiring 5G small cells. Regarding the availability of 5G spectrum, the 3.5 GHz band has been fully allocated to MNOs, preventing local actors (i.e., cities) from directly providing broadband services. Nevertheless, according to the spectrum license agreement, MNOs have an obligation to offer a local license if they cannot serve a service request from a local customer<sup>5</sup>.

## 2 Related work

### 2.1 Neutral infrastructure/host

The neutral host concept has been studied as a business model for telecom operators. This concept is studied in the H2020 5GCity project to increase revenues for European telecom companies (Neokosmidis et al., 2018). The neutral host concept is also studied in the 5G ESSENCE project to enable infrastructure sharing among multiple operators, allowing network customization on a per-tenant basis (Chochliouros et al., 2017). A neutral host micro operator model is defined in (Kibria et al., 2017) to customize wireless services according to local requirements, while benefiting involved economic actors. Finally, in the LuxTurrim5G project, a neutral host operator model is devised to lead a business ecosystem that aims to deploy 5G small cells on light poles, providing a city-wide deployment (Benseny, Walia, Hämmäinen, & Salmelin, 2019). The cited references tend to agree on

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<sup>1</sup> Long-term planning can include the deployment of city-owned edge cloud network, avoiding latencies from inter-MNO edge cloud handover.

<sup>2</sup> Low latency services will be enabled by 5G selective traffic routing (3GPP, 2018a) and ETSI MEC (ETSI, 2018b).

<sup>3</sup> The NHO can be seen by MNOs as a competitor instead of a complementor. E.g. it provides wireless-fixed access via local licensing.

<sup>4</sup> Finland has a base station density of 3.7 LTE eNB per 1000 population, which means Helsinki has, at least, 2380 base station sites operating LTE bands.

<sup>5</sup> The Finnish spectrum policy has traditionally aimed to allocate spectrum to MNOs in an equitable manner. In more detail, the Finnish National Regulatory Authority (NRA) allocated an equal amount of spectrum from the 700 MHz, 800 MHz, 1800 MHz, 2.6 GHz, and 3.5 GHz band to the three competing MNOs (FICORA, 2017).

the fact that a neutral host infrastructure can be disruptive to existing business models by providing need-based multi-tenancy to existing and new entrants alike. A city driven neutral infrastructure can also be seen as a subsidy to existing and new entrants who can start providing their services without investing in physical infrastructure.

## 2.2 5G network slicing

Network slicing offers a means to create virtual networks to satisfy use case specific network requirements. Network slicing can be broadly defined for three service types; enhanced Mobile Broadband (eMBB), massive Internet of Things (mIoT), and Ultra-Reliable Low Latency Communications (URLLC) (3GPP, 2018a). Technically, a network slice instance is formed by chaining network slice subnet instances. These network slice subnet instances can belong to different network domains comprising of the required virtualized network functions (ETSI, 2018a). Network slicing will enable network sharing and dynamic allocation through virtualization of physical network resources such as radio access networks, core network, and other computing, storage, and radio resources (licensed spectrum). Through network slicing, a city-driven neutral host operator can run its dedicated services through use case specific slices and securely share its neutral infrastructure with MNOs. A shared neutral infrastructure will reduce network deployment costs by avoiding heavy densification by multiple MNOs and enable new revenue streams for the city.

## 2.3 5G radio performance

Field tests for 3.5 GHz, deployed on macro sites can provide similar coverage as LTE at 2100 MHz (Halvarsson et al., 2018; Nokia White paper, 2018). Network operators in Finland own 800, 1800 and 2100 MHz LTE bands with 10, 20 and 20 MHz bandwidths, allowing a maximum aggregated bandwidth of 50 MHz through interband carrier aggregation (Valtonen, 2015). The average cell spectral efficiencies for LTE have been found to be between 1.56-1.86 bps/Hz, allowing an average cell capacity of 93 Mbps (Liu et al., 2017; Oughton & Frias, 2017). The higher spectral efficiencies 10 bps/Hz and wider bandwidth of 5G can provide higher cell throughputs (Gupta & Jha, 2015). Several 5G trials have achieved spectral efficiencies of above 8 bps/Hz, with average cell spectral efficiencies between 2.71-4.62 bps/Hz and with time it can be expected that the efficiency of the 5G NR will improve further (Liu et al., 2017; Nokia White paper, 2018). With such high spectral efficiencies and over 100 MHz bandwidth, the throughputs of above 800 Mbps are expected over 3.5 GHz band.

# 3 Method

## 3.1 Feasibility of the neutral host operator

The NHO offers a network resource that MNOs can use to extend 3.5 GHz-based (and potentially 26 GHz-based) outdoor capacity and coverage. In the long run, this coverage may be extended to reach city-wide levels. Therefore, NHO revenues are collected from MNOs via usage fees from 5G network slices. Hence, on the revenue side, the feasibility of the city-driven NHO depends on the fraction of outdoor traffic that is offloaded by MNOs. However, the deployment of BSs on light poles requires substantial deployment costs. Existing light poles need to be replaced with new poles capable of housing BSs. Moreover, public works are required to connect light poles to existing fiber and power networks since the existing cables may not be enough. Hence, on the cost side, the feasibility of the NHO depends on the cost-saving strategies to reduce usage fees. Note that MNOs may not offload traffic if fees do not significantly lower the cost per bit in comparison to their own small cell cost calculations.

Next we summarize cost-saving mechanisms:

- A city-driven light pole-based deployment does not require per-site negotiation with venue owners since the city is the sole owner of poles.
- The installation of small cells in dense urban areas requires specific per-cell work, which is unique to the site. In a light pole-based deployment, small cell installation can be significantly simplified since smart light pole designs typically account for the hosting of mobile antennas, thus providing cost savings in future large-scale deployments.
- The maintenance of network equipment in light poles can be simplified as smart light pole design becomes standardized. In addition, the equipment is easily accessible at the street level, and maintenance visits do not require access to locked premises.
- The installation of the smart poles themselves can coincide with the ordinary renewal of light poles, which typically occurs every 30 years.
- The installation of smart poles cannot only be associated with mobile services since these poles can support other services, such as the charging of electrical vehicles, the housing of sensors, etc.
- In comparison to non-coordinated independent market-driven deployments, a city-driven light pole-based deployment can achieve significant reduction in public work costs (for large scale deployments) if the required digging and ducting (to connect smart lights poles to existing power and fiber networks) is coordinated between fiber owners (i.e., MNOs, power companies, fiber operators, city-owned infrastructure).
- A city-driven deployment can accelerate impact studies and the issue of permits.

### 3.2 Cost comparative analysis

We examine two deployment strategies, both assuming that MNOs first update existing macro sites with BSs working at 3.5 GHz. In the *MNO-competition-based strategy*, MNOs deploy new 3.5 GHz small cells following a market-driven deployment. Conversely, in the *NHO-driven strategy*, these cells are deployed by the NHO. To compare the costs of these strategies, we forecast future mobile network usage based on estimations on the current usage (steps 1-2 in Figure 1). To test this sensitivity of the model regarding future usage, we define three alternative growth scenarios:

- Baseline: no growth, i.e., a constant number of SIMs, 2.07 (GSMA Intelligence, 2018) per user are assumed from 2020-2030
- Medium: a medium growth is assumed leading to 2.5 SIMs per user by 2030
- High: a high growth is assumed leading to 3.0 SIMs per user by 2030

Next, we estimate the updated network capacity that results from updating existing macro sites with 3.5 GHz base stations (steps 3-4). Based on results, we estimate deployment costs for the *MNO-competition-based strategy* and for the *NHO-driven strategy* to bridge the capacity gap between updated network capacity and future network usage (step 5a/b). Further three cases are defined where NHO achieves low, medium, and high-cost savings by reducing public work costs. Finally, we compare the costs of the two deployment strategies to identify the traffic levels and cost saving/sharing strategies that would induce MNOs to use and share the light pole-based infrastructure instead of deploying their small cell network (step 6). The cost comparison is conducted on a per postal code basis.

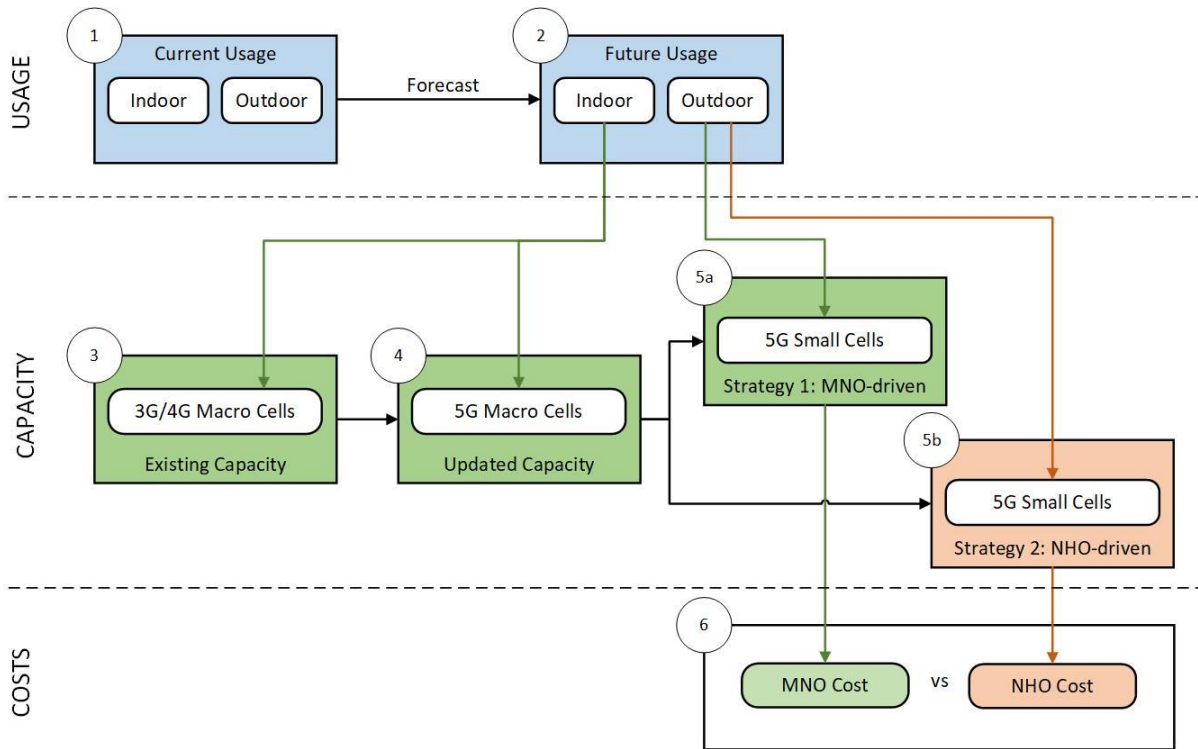


Figure 1 Cost comparative analysis

## 4 Analysis

### 4.1 Helsinki Metropolitan Area

The Helsinki Metropolitan Area includes 1,126,548 inhabitants across the municipalities of Helsinki, Espoo, Vantaa, and Kauniainen. Among the mentioned municipalities, Helsinki has the largest population in absolute value, i.e., 628,760 inhabitants as of 2017. Helsinki also has the postal codes with the highest population density with a mean postal code population density of 4,252 inhabitants per square kilometer.

Postal code socio-economics and physical characteristics are extracted from the open Paavo repository produced by Statistics Finland (Official Statistics of Finland, 2019). The repository provides statistics at the postal code level for the 3036 postal codes of mainland Finland. From this repository, we extract the population as a proxy for the number of mobile broadband users (*total\_users*) and the area (*postal\_code\_area*).

In this study, we only consider 135 postal codes out of the 167 in the Helsinki Metropolitan Area. We discard postal codes because of unknown population (i.e., the population is lower than 30 thus statistics are available due to privacy requirements), low population density (i.e., less than 700 inhab/km which is typically considered the minimum population density for suburban areas), extremely small postal code area (i.e., postal codes with less than 200 km<sup>2</sup> which may get coverage from adjacent postal codes), a significant postal code area is fragmented into islands. Figure 2 depicts the population density for the 135 postal codes included in the study<sup>6</sup>.

<sup>6</sup> Figure 2 employs a choropleth map with a blended hue color progression. Postal codes are grouped following a geometrical interval classification, thus balancing the number of postal codes per class versus interval length.

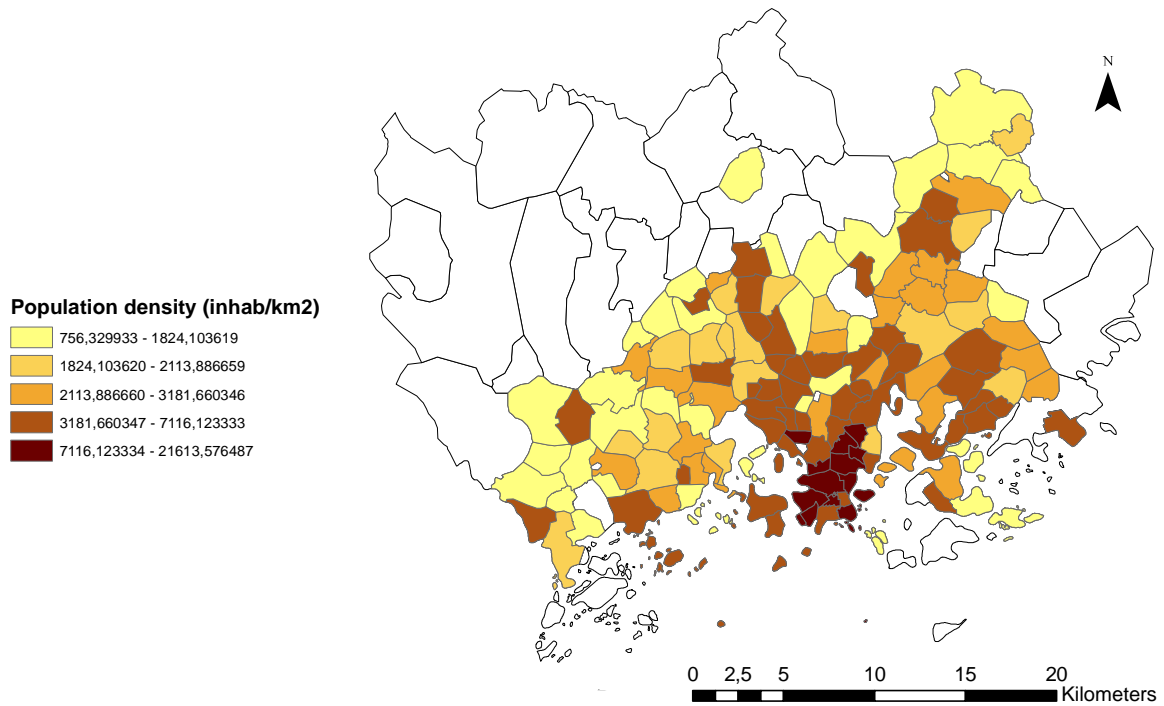


Figure 2 Population density (inhab/km2) in postal codes of the Helsinki Metropolitan Area

## 4.2 Current and Future Network Usage

### 4.2.1 Daily peak usage

We estimate the current network usage by calculating the daily peak usage per second in Mbps, as follows:

$$\text{daily\_peak\_usage} = \text{total\_users} * \text{SIMs\_per\_user} * \text{SIM\_daily\_usage} * \text{peak\_hour\_fraction}$$

$$\text{where } \text{SIM\_daily\_usage} = [\text{SIM\_monthly\_volume} / (3600 * 30)]$$

where *SIMs\_per\_user* is the average number of SIMs per user in Finland, i.e., 2.07 as of Q2 2018 according to (GSMA Intelligence, 2018), *SIM\_monthly\_volume* is the amount of data that Finnish users consume on average every month per SIM, i.e., 18.49 GBs as of Q2 2018 according to the Finnish regulator (Traficom, 2019), and *peak\_hour\_fraction* is the fraction of daily usage in peak hour depending on the postal code, i.e., 10.1% for residential postal codes.

This calculation makes several simplifying assumptions. For example, we assume that postal code areas can be roughly divided into two distinct types with different peak hour fractions. Additionally, we assume that the monthly usage per SIM and number of SIMs per subscriber do not vary significantly between postal code areas.

We estimate future network usage by forecasting values for the variables in the calculation of *daily\_peak\_usage*. We assume that the main drivers of traffic growth will be an increase in volume consumption per SIM (i.e., *SIM\_monthly\_volume*) and the emergence of connected devices. We assume the same *SIM\_monthly\_volume* for both traditional mobile broadband and connected device subscriptions since it is likely that traffic from connected devices is indirectly generated by humans (e.g., car entertainment systems as a source of outdoor traffic, 5G smart TVs as a source of indoor traffic). We don't expect narrow band IoT to significantly drive traffic growth.

First, we forecast the future *SIM\_monthly\_volume* through a piece-wise regression model with logistic growth. Specifically, the model is fit (using maximum a posteriori parameter estimation) over the empirical network usage volumes from 2011 to 2019 (reported biannually by the Finnish regulator) (Traficom, 2019). The fitting also assumes a maximum carrying capacity of 100 GB/SIM/month for the logistic growth. This 100GB capacity is simply a reasonable guess that allows a plausible forecast. In practice, both the model fitting and forecasting uses the python-based Prophet forecasting library (Taylor & Letham, 2018). For reference, Figure 3 illustrates the empirical monthly data volume (in GB) per SIM along with the regression model and forecasts up to 2030. The model fits well the empirical data.

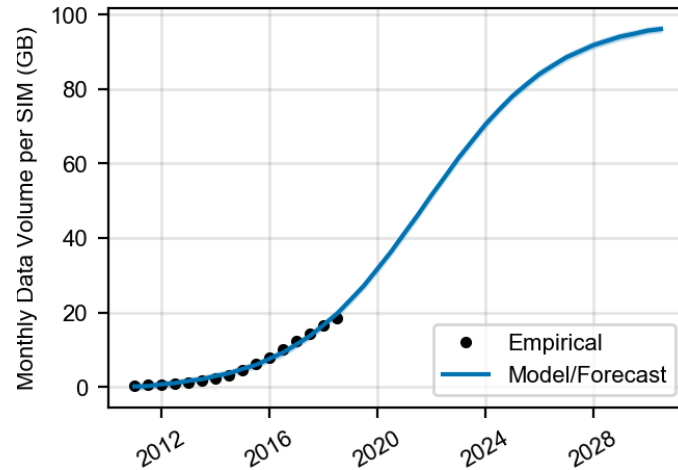


Figure 3 Empirical monthly data volume per SIM and fitted model/forecast up to 2030

Second, we assume that *total\_users* and *peak\_hour\_fraction* do not change substantially over the time frame, thus assuming a constant value is simply a conservative guess<sup>7</sup>. Third, we account for the increase in subscriptions per user by splitting *SIMs\_per\_user* into broadband and connected devices components similar to (Bao et al., 2017), as follows:

$$SIMs\_per\_user = broadband\_SIMs\_per\_user + connected\_devices\_SIMs\_per\_user$$

The *broadband\_SIMs\_per\_user* is kept constant at 2.07 since, in Finland, it has not experienced changes from 2011 to 2018, according to (GSMA Intelligence, 2018). In contrast, we make *connected\_devices\_SIMs\_per\_user* vary to simulate three alternative scenarios with different growth, including no growth (constant *SIMs\_per\_user* = 2.07), medium growth (*SIMs\_per\_user* reaches 2.5 by 2030), and high growth (*SIMs\_per\_user* reaches 3 by 2030).

#### 4.2.2 Indoor/Outdoor demand

We estimate the fraction of indoor versus outdoor traffic (in Mbps) by splitting the *daily\_peak\_usage* value as follow:

$$outdoor\_traffic\_demand = outdoor\_traffic\_fraction * daily\_peak\_usage$$

$$indoor\_traffic\_demand = (1 - outdoor\_traffic\_fraction) * daily\_peak\_usage$$

where *outdoor\_traffic\_fraction* accounts for the traffic generated by SIMs that are permanently or spend some time of the day outdoor, and thus can be served by both macro cells and outdoor small

<sup>7</sup> Although the population of Helsinki is expected to grow by between 7,000 and 8,000 inhabitants per year, projections are not available at the postal code level for the Helsinki Metropolitan Area (Helsinki City, 2018). Similarly, projections for the number of workplaces are also not available.

cells. We assume the value of *outdoor\_traffic\_fraction* to be constant at 20% and not increasing over time, as a conservative assumption.

### 4.3 Existing Network Capacity

We estimate the existing mobile network capacity in postal codes based on the required number of 4G sites (*4G\_macrocell\_sites*) to satisfy either coverage or capacity requirements. To satisfy coverage requirements, we assume a large 4G base station coverage, i.e., 0.29 km<sup>2</sup> (Yunas, Niemela, Valkama, & Isotalo, 2014), given that the Helsinki Metropolitan Area currently has essentially 100% 4G coverage (Rewheel, 2019). Further, we satisfy capacity requirements (i.e., the *daily\_peak\_usage* for 2019) assuming that 4G sites include 3 cells, each of which with a capacity of 93 Mbps, as shown in Table 1. While spectrum efficiency values are extracted from (Liu et al., 2017; Oughton & Frias, 2017). The employed spectrum corresponds to the sum of all 4G bands allocated to individual MNOs in Finland. As a result, cell throughput is a theoretical maximum values. As a result of this calculation, the following proxy variables are produced for future use: *4G\_macrocell\_sites* and *total\_macrocell\_throughput*.

Table 1 Cell throughput

Variable	Calculation	Value	Proxy code
4G marco cell throughput	50 MHz * 1.86 bit /Hz	93 Mbps	<i>4G_macro_cell_throughput</i>
5G marco/small cell throughput (at 3.5 GHz)	130 MHz * 3 bits/Hz	390 Mbps	<i>5G_macro_cell_throughput</i>

### 4.4 5G deployment

#### 4.4.1 Update of existing sites

We assume that MNOs first update existing 4G sites with Massive MIMO antennas working at 3.5 GHz. As a result, MNOs achieve a 3.5 GHz-based coverage that is similar to existing 2.6 GHz deployments since Massive MIMO antennas working at 3.5 GHz deployed on rooftops can provide similar coverage as antennas working at 2.1 GHz (Halvarsson et al., 2018; Nokia White paper, 2018). In our calculation, we add macro cell capacity to postal codes as the existing network capacity becomes used. First, we estimate the yearly spare capacity as network usage increases, as follows:

$$\text{spare\_macrocell\_capacity}(\text{year}_i) = \text{total\_macrocell\_throughput}(\text{year}_{i-1}) - [\text{daily\_peak\_usage}(\text{year}_i) * \text{guard\_capacity}]$$

where *spare\_capacity* (*year<sub>i</sub>*) is the unused postal code capacity in year *i*, and *guard\_capacity* is a safeguard that operators keep avoiding congestion and overloading equipment, i.e., 20% of *daily\_peak\_usage*. Second, we add more capacity, as follows:

$$\text{additional\_macrocell\_throughput} = p * \text{cells\_per\_site} * \text{5G\_macro\_cell\_throughput}$$

$$0 < p < \text{4G\_macrocell\_sites}$$

where *p* is the number of updated 4G sites, *cells\_per\_site* equals 3 as the standard 4G site configuration, and *5G\_macro\_cell\_throughput* is defined in Table 1. Given the significant difference between 4G and 5G cell throughput (i.e., almost 4 times larger), we assume a rapid uptake of 5G broadband services and that new usage is only served by 5G cells. Existing 4G macrocell capacity is then used by narrowband M2M subscriptions.

#### 4.4.2 Small cell deployment for offloading outdoor traffic

We assume that MNOs and the NHO deploy small cells when there are no more 4G sites to be updated. The number of small cells is calculated to serve the *outdoor\_traffic\_demand*. To this end, we first calculate the spare capacity in small cells, as follows:

$$\begin{aligned} \text{spare\_smallcell\_capacity}(\text{year}_i) = & \text{total\_small\_cell\_throughput}(\text{year}_{i-1}) - \\ & [ \text{outdoor\_traffic\_fraction} * \text{daily\_peak\_usage}(\text{year}_i) * \text{guard\_capacity} ] \end{aligned}$$

Second, we update the existing postal code capacities, as follows:

$$\begin{aligned} \text{total\_smallcell\_throughput}(\text{year}_i) = & \text{total\_smallcell\_throughput}(\text{year}_{i-1}) \\ & + m * 5G\_small\_cell\_throughput \end{aligned}$$

where  $m$  is the number of small cells required to satisfy the *spare\_smallcell\_capacity*. Note that small cells only have one cell in contrast to macrocells, which have 3 cells. Third, we check that macro cell capacity can serve indoor demand, as follows:

$$\begin{aligned} \text{spare\_macrocell\_capacity}(\text{year}_i) = & \text{total\_macrocell\_throughput}(\text{year}_{i-1}) - \\ & [ \text{indoor\_traffic\_fraction} * \text{daily\_peak\_usage}(\text{year}_i) * \text{guard\_capacity} ] \end{aligned}$$

In case the resulting macro cell capacity after offloading it is not enough to satisfy indoor demand, we assume that MNOs deploy new macrocells (or micro-operators deploy indoor small cells). We increase the macro cell capacity as follows:

$$\text{additional\_macrocell\_throughput} = q * \text{cells\_per\_site} * 5G\_macro\_cell\_throughput$$

where  $q$  is the number of new 5G macrocell sites.

#### 4.4.3 Results

Figure 4 illustrates the deployment of 5G base station sites from 2020 to 2030. Existing 4G sites are updated throughout the deployment period. About 85%, 90%, and 92%, of existing macro sites will have to be updated to 5G by 2030 in the baseline, medium, and high growth scenarios. New outdoor small cells begin to be deployed from 2025, as the increase in outdoor traffic exceeds the capacity supplied by updated macro sites. The baseline, medium, and high growth scenarios require 34, 816, and 1035 new small cells to be deployed to serve the exceeding outdoor capacity demand. Further, from 2026, new macro sites by the MNOs or new indoor small cells by local operators will have to be deployed to serve the exceeding indoor traffic demand. Although the updated macro sites provide significant 5G coverage update, high population postal codes still demand a higher capacity. Postal codes with higher population exert more capacity demand and require a relatively high number of small cells. 5G small cells rollout in the Helsinki metropolitan area is illustrated in Figure 5.

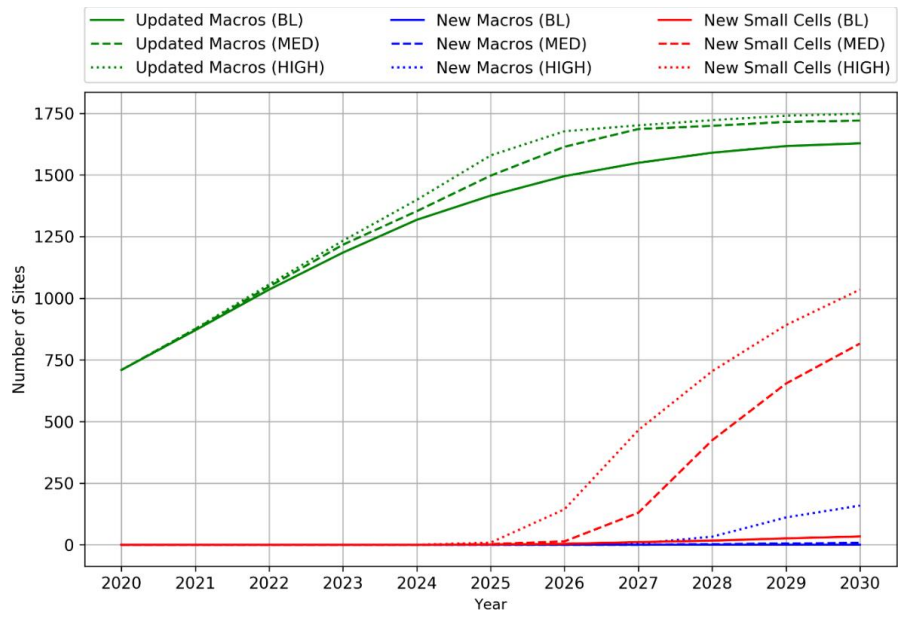


Figure 4 Deployment of 5G base station sites from 2020 to 2030

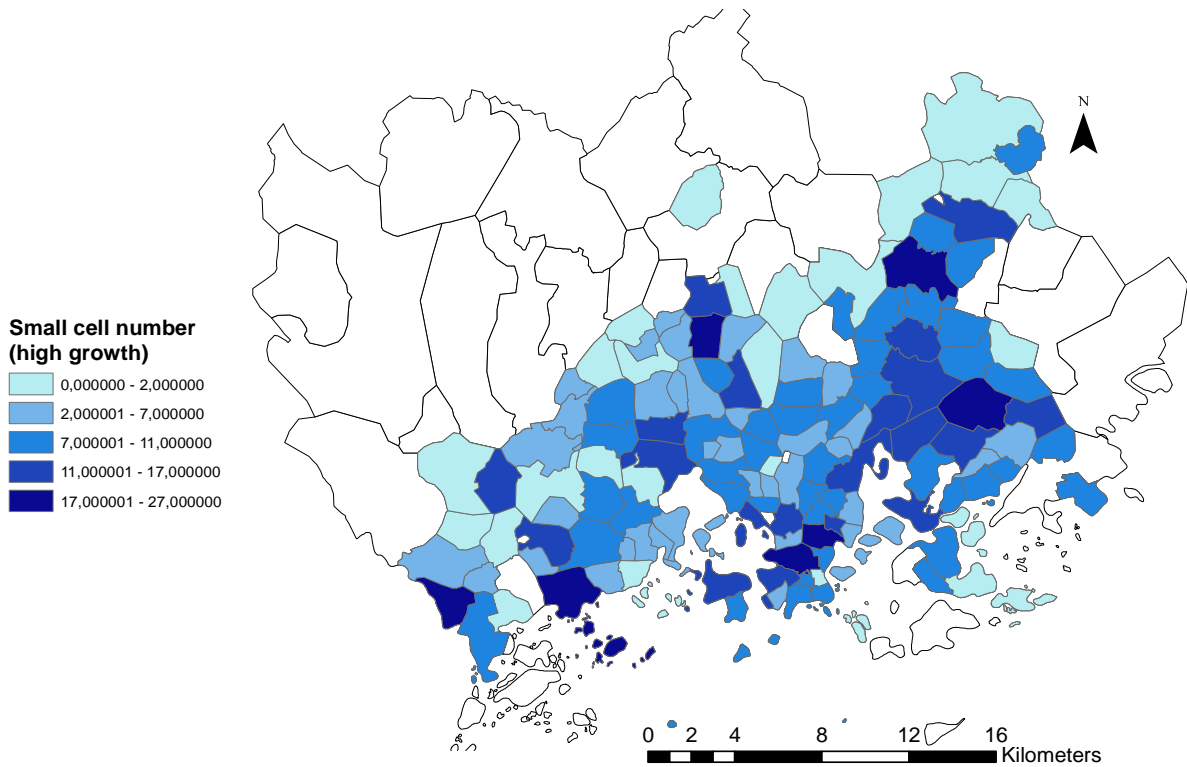


Figure 5 Outdoor 5G small cells rollout by 2030

## 4.5 Cost comparison for small cells

We estimate the costs of deploying small cells for the *MNO-competition-based strategy* as well as for the *NHO-driven strategy*, and we identify the number  $m$  of small cells providing cost equilibrium. These two deployment strategies differ in their cost structure (which we indicate with different equations) and in the values of individual variables (which we indicate with different variable names, e.g., *non\_lightpole\_bs\_installation* VS. *non\_lightpole\_bs\_installation*). Finally, we simulate three cases in which the NHO is able to reduce public work costs thanks to volume discounts since the NHO digs the full length of streets instead of digging in a per-small cell basis (i.e., 80%, 70%, and 60% of *cost\_of\_digging\_and\_ducting*).

### 4.5.1 MNO-competition-based strategy

MNOs independently deploy new small cells in the main street intersections of postal code. More precisely, they lay new fiber from their existing macro/small cells up to the new small cell locations. We estimate cost, as follows:

$$\begin{aligned} \text{cost of new non-light pole 3.5 GHz small cells} = \\ m * (5G\_small\_cell\_bs + non\_lightpole\_passive\_equipment + non\_lightpole\_bs\_installation + \\ non\_lightpole\_public\_works + venue\_owner\_negotiation) \end{aligned}$$

where  $m$  is the number of small cells, and *5G\_small\_cell\_bs* is the cost of base stations including antennas and transmission equipment, *non\_lightpole\_passive\_equipment* includes the cost of masts and other supporting structures, *non\_light\_pole\_bs\_installation* is the cost of BS installation, *venue\_owner\_negotiation* is the cost of the negotiation between the MNO and the venue owner (e.g., about the site rental conditions). Finally, the *non\_lightpole\_public\_works* is estimated as:

$$non\_lightpole\_public\_works = cost\_of\_digging\_and\_ducting * distance\_A$$

$$we\ estimate\ distance\_A\ as\ the\ average\ inter\_intersection\ distance$$

note that Helsinki has one of the smallest inter-intersection distance in Europe with a median value of 42 meters (Boeing, 2018). Hence, we estimate *distance\_A* as *inter\_light\_pole\_distance* of 200m.

### 4.5.2 NHO-driven strategy

The NHO deploys new small cells in some, key light poles along main streets. For this, it lays new fiber along the whole street first, thus easing the future deployment of base stations. We estimate additional capacity and cost, as follows:

$$\begin{aligned} \text{cost of new light pole 3.5 GHz small cells} = \\ m * (5G\_small\_cell\_bs + lightpole\_passive\_equipment + lightpole\_bs\_installation) + \\ lighpole\_public\_works \end{aligned}$$

where *light\_pole\_bs\_installation* is the cost of BS installation and *lightpole\_passive\_equipment* includes the cost of hardware attaching the cell to the post. Finally, the *lightpole\_public\_works* accounts for fully digging and ducting the full length of streets. A new street is dug when all light poles in the previous streets are equipped with small cells, according to *inter\_light\_pole\_distance* of 200m.

$$lightpole\_public\_works = cost\_of\_digging\_and\_ducting * number\ of\ streets * street\_length$$

$$street\_length = diameter\ of\ the\ circle\ with\ an\ equal\ area\ than\ the\ postal\ code$$

#### 4.5.3 Cost assumptions

Table 2 summarizes the cost values and assumptions considered in the cost comparison. Some NHO cost savings are here visible when comparing *light pole* VS. *non\_lightpole* variables. These cost savings will be studied further in the future via more robust methods, e.g., Monte Carlo simulations.

Table 2 Cost items

Variable	Value	Rationale
5G_small_cell_bs <sup>8</sup>	4.520 €	5G NORMA project <sup>9</sup>
non_light_pole_passive equipment	50% of 5G_small_cell_bs	Assumption
lightpole_passive equipment	50% of non_light_pole_passive equipment	NHO cost saving
non_lightpole_bs_installation <sup>10</sup>	800 €	5G NORMA project
lightpole_bs_installation	20% of non_lightpole_bs_installation	NHO cost saving
venue_owner_negotiation	1.400 €	Assumption
cost_of_digging_and_ducting <sup>11</sup>	180 €/m	LuxTurrim5G project <sup>12</sup>

#### 4.5.4 Results

Figure 6 shows the cost evolution of MNO-/NHO-driven strategies for the scenario with a medium growth on connected devices subscriptions. the same for the high growth scenario. These figures only show one cost calculation for the MNO-driven strategy (solid line), but three calculations for the NHO-driven strategies (dashed line) each of which accounts for public works cost reductions (i.e., 80%, 70%, and 60% of *cost\_of\_digging\_and\_ducting*).

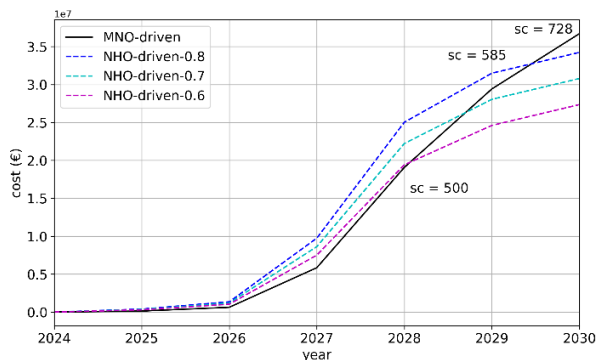


Figure 6 Cost comparison for medium traffic growth

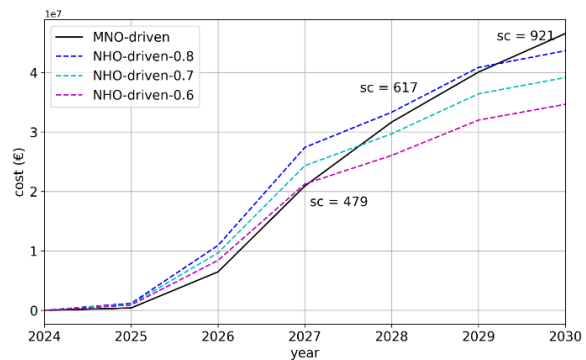


Figure 7 Cost comparison for high traffic growth

In the medium growth scenario, when public work savings are at 60%, the NHO-driven strategy becomes more affordable than the MNO-driven in 2028 with 500 small cells. Cost equilibrium is also reached in 2028 with 585 small cells when public work savings at 70%. Finally, at 80% level cost equilibrium is reached in 2029 with 728 small cells.

As expected, in the high growth scenario, equilibrium points are achieved earlier, i.e., already in 2027 for 60% and 70% public work saving levels. For the 80% case, cost equilibrium is reached in 2029. Regarding the number of small cells, while it is smaller for the 60% case (i.e., 479 small cells), it is larger

<sup>8</sup> New 5G outdoor small cell including antenna and baseband processing.

<sup>9</sup> Costs from the 5G-NORMA project are transformed as 1 GBP = 1.13 EUR (Ajibulu, Bradford, Chambers, Karousos, & Konstantinou, 2017)

<sup>10</sup> Feeder, install and test and commission costs per site.

<sup>11</sup> Digging and ducting accounts for asphalt pavement removal, digging, ducts, and walkside restoration in city centers.

<sup>12</sup> Cost items have been extracted during expert interviews involved in the LuxTurrim5G project from Finnish cities, network equipment vendors, MNOs, and SMEs.

for the other two cases (617 and 921 small cells ) in comparison to the medium growth scenario. This result may be caused by multiple factors, e.g., postal codes requiring small cells have on average a longer street length than in the medium growth scenario

## 5 Conclusions

In this paper, we have analyzed the feasibility of a city-driven NHO for the case of the Helsinki Metropolitan Area by comparing the costs of two alternative small cell deployment strategies. To this end, we suggest three future network usage scenarios, each of which assumes a larger increase in data volume consumption for mobile broadband as well as in the number of subscriptions for connected devices. In our model, MNOs update existing 4G sites with 3.5 GHz-based MIMO antennas before small cells are deployed for offloading outdoor traffic, if needed. Results show that by 2030, about 85%, 90%, and 92% of existing 4G macro sites will have to be updated with 5G, and additionally 34, 816, and 1035 outdoor small cells will be required, in the baseline, medium, and high growth scenarios respectively. During the initial years of deployment, the NHO-driven strategy incurs higher costs than the MNO-driven strategy. However, before 2030, the NHO-driven strategy presents lower accumulated deployment costs for all demand scenarios. In case the NHO-driven strategy achieves a 20% cost-savings in public works, this strategy becomes less costly than the MNO-driven in 2029 with 728 small cells and with 921 small cells for the medium and high growth scenario, respectively. Although a city-driven light pole-based deployment can benefit from multiple cost-saving mechanisms, these mechanisms should focus on reducing the cost of public works since it represents the largest contributor to the deployment cost.

## 6 Future work

Future work will study further the key technical and economic factors that make the city-driven NHO successful, including but not limited to:

- Minimum utilization levels of the neutral infrastructure that justify city investment
- Pricing structures for 5G network slices, enabling the city to recover investments with different payback times
- Competition implications (i.e., from infrastructure-based to service-based competition models)

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