Shared Antennas, Shared Risks

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***Abstract*—As critical systems increasingly rely on machine-to-machine (M2M) communications, the demand for highly resilient connectivity has never been greater. While multipath protocols are often used to switch between different access technologies, they can also leverage multiple providers for the same type of access technology to enhance resilience. New multipath communication protocols have emerged to utilize multiple network interfaces simultaneously, offering more stable and robust mobile connections. However, a key question remains: Which operators should be selected to achieve truly resilient connections? To address this, we collected and analyzed public data to identify the locations of sites, the antennas installed at these sites, and the operators using these antennas, including the evolution of antenna sharing over time. In some cases, we also obtained details about the manufacturers and models of the antennas. Our analysis reveals the extent of antenna sharing among operators and the associated risks to resilience. Such an analysis is essential for selecting operators for critical systems relying on multipath communication protocols.**

***Index Terms*—Machine-to-machine communications, Mobile communication, 5G mobile communication, Radio access networks, Mobile antennas, Fault tolerance, Telecommunication network reliability.**

I. Introduction

As reliance on machine-to-machine (M2M) communications in critical systems continues to grow, the need for highly resilient connectivity has become more pressing than ever.

Several approaches can achieve this resilience. The first involves deploying a dedicated communication network, but this solution is costly, complex to implement, and typically limited to a restricted geographic area. This is the case, for instance, for the railway industry, which uses a dedicated GPS-R technology [1] on the one hand, while also deploying private 5G networks [2]. An alternative is to leverage existing communication networks, such as commercial cellular networks. This can be done by purchasing a dedicated network slice, though this remains expensive. An emerging, more cost-effective and flexible solution involves using multiple cellular networks simultaneously, employing multi-path transport protocols like Multipath TCP (MPTCP) [3] or Multipath QUIC (MPQUIC) [4]. These protocols distribute data across multiple communication paths, enhancing resilience in case of path failure. By redistributing traffic to other paths, this ensures that the connection remains stable and its state is preserved during an outage. By using several cellular networks in parallel, M2M systems can achieve more reliable and resilient connectivity, even in the event of network failure or congestion [5]. Additionally, multi-path protocols improve performance by optimizing available bandwidth usage [6]. Ultimately, the simultaneous use of multiple cellular networks with multi-path protocols offers an economical and flexible solution for ensuring resilient connectivity in critical M2M systems.

However, this approach raises new questions, particularly regarding the selection of cellular networks. To ensure resilient connectivity, it is crucial to choose networks that offer good coverage and high service quality. While coverage and performance reports from regulators and operators could serve as a starting point, these metrics alone are insufficient to guarantee optimal resilience.

Indeed, the increasing centralization of the Internet introduces single points of failure (e.g., Cloudflare outages [7] [8]). Cellular networks are not immune to this trend and are also vulnerable to centralized system failures [9] [10]. Indeed, mobile network operators increasingly share infrastructure, whether at the sites' level or even at the antenna level (via shared Radio Access Network (RAN)), while MVNOs (Mobile Virtual Network Operators) rely entirely on third-party infrastructure.

Furthermore, the mobile network equipment sector is dominated by a handful of major players, which poses a risk in the event of bugs, hardware or software vulnerabilities from a manufacturer, particularly if an operator's equipment inventory lacks diversity.

We will therefore examine two components of cellular infrastructure resilience: geographic diversity, through the evolution of infrastructure sharing among major operators in France from 2018 to 2026, and manufacturer diversity, through a study of equipment concentration in Wallonia, Belgium.

II. Background

Before analyzing infrastructure sharing and its implications, it is necessary to clarify what we mean by network resilience in this context. Network resilience is the ability of a network to resist incidents, whether isolated or stemming from a common cause [11]. Cellular infrastructure resilience is itself a broad topic, encompassing many dimensions such as physical hardening, backhaul redundancy, cybersecurity, spectrum availability, and coverage resilience. This paper does not address all of these dimensions. Instead, it focuses on

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two that we consider critical components of cellular infrastructure resilience: geographic diversity, when redundant components are physically separated, and manufacturer diversity, when equipment originates from different vendors, limiting common-cause failures. A common thread across resilience dimensions is the need for both redundancy, the replication of network elements so that the loss of one does not interrupt service, and diversity, the avoidance of shared points of failure between redundant components. Multipath protocols such as MPTCP and MPQUIC exploit redundancy across operators, yet redundancy alone is insufficient if the underlying paths lack diversity. While geographic and manufacturer diversity do not exhaust the full scope of cellular infrastructure resilience, they are therefore directly relevant to the operator selection problem in multipath deployments. To understand how infrastructure sharing affects these diversity properties, we first describe the architecture of mobile networks and the levels at which sharing can occur.

The architecture of a mobile network can be divided into three main components: the Radio Access Network (RAN), the transport network, and the core network. The RAN consists of base stations that communicate with mobile devices (UEs). The transport network connects these base stations to the core network. The latter handles switching and routing functions to direct calls and data to their final destination. This architecture varies depending on the technology used (GSM, UMTS, LTE, 5G). For instance, 5G networks employ a more flexible and decentralized architecture, leveraging virtualized network functions and cloud-deployable services, unlike UMTS and LTE networks, which rely on a more centralized architecture with physical network elements.

While UMTS and LTE networks were already used for machine-to-machine (M2M) communications and the Internet of Things (IoT), 5G offers significant advantages for these applications, particularly in terms of performance and latency. It is especially well-suited for real-time critical applications, such as autonomous vehicles, thanks to features like network slicing [12], which enables the creation of specialized virtual networks for different applications.

There are two types of mobile operators: Mobile Network Operators (MNOs), which own and operate their own network infrastructure, and Mobile Virtual Network Operators (MVNOs), which lease access to an MNO's infrastructure to provide services to their customers. MNOs are thus responsible for the architectural and technological choices of their networks.

MNOs play a central role in the development and deployment of mobile networks and enjoy a stronger and more serious reputation than MVNOs, which are often seen as secondary players. For deploying applications using multipath communications, MNOs appear more relevant, as their own infrastructure could ensure the use of distinct networks. However, this is not always guaranteed, as some MNOs share infrastructure elements.

Indeed, certain infrastructure elements can be shared among multiple MNOs: from the site, a physical location (mast, rooftop, or tower) hosting the antennas, up to the full RAN, where multiple operators share the access network infrastructure. There are two main sharing configurations [13]: Multi-Operator Core Network (MOCN) and Gateway Core Network (GWCN). In MOCN, multiple operators share their RAN but maintain separate core networks, making it the most common configuration. In GWCN, operators share both the RAN and part of their core network, a setup that is less common and usually reserved for specific scenarios with closer operator agreements.

In an MOCN configuration, two options exist for RAN sharing: using distinct frequency bands for each MNO or sharing the same frequency bands (spectrum pooling) [14]. The latter allows for more efficient use of the radio spectrum by pooling resources based on demand.

These sharing practices differ fundamentally from MVNOs, which rely entirely on MNO infrastructure without owning any themselves, as well as from network slicing. The latter technology enables the creation of specialized virtual networks within a single operator's infrastructure.

For the remainder of our analysis, we were unable to precisely determine the type of infrastructure sharing between MNOs. We will therefore refer to antenna sharing, as this is the only element whose sharing we could confirm with certainty. However, it is highly likely that MNOs also share other equipment, thus operating in an MOCN configuration. This assumption is particularly plausible for smarter active antenna systems (AAS) [15], such as Nokia's AirScale AAU used for 5G transmissions, which integrate multiple network functions into a single active device and must work in close coordination with the scheduler to operate effectively, unlike traditional passive antennas.

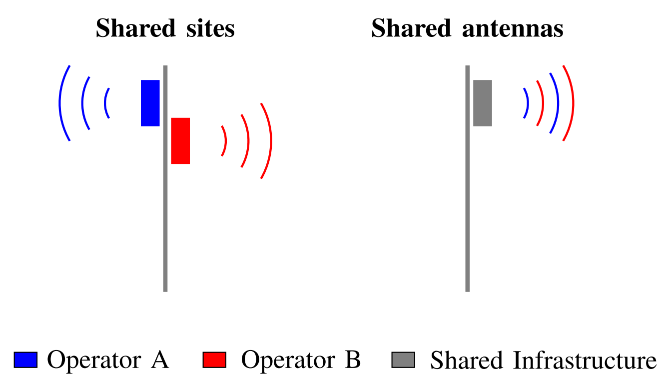

Fig. 1. Illustration of the difference between shared sites and antennas sharing.

To summarize, as illustrated in Figure 1, we designate installations where passive equipment (power supply, towers) is shared among MNOs as shared sites, and we refer to cases where MNOs use the same antennas for radio transmission as shared antennas.

III. Related Work

Infrastructure sharing among telecommunications operators is not a novel concept, and extensive research has examined various forms of sharing, their benefits, and associated challenges [16] [17] . However, the majority of existing studies focus on the economic [18] [19] and operational aspects [20] [21] of infrastructure sharing , without thoroughly analyzing the implications for mobile network resilience.

Regulatory reports and legal frameworks similarly present gaps in addressing network resilience. While telecommunications regulators in Europe provide extensive data on network coverage and performance [22] [23] [24], their analysis of infrastructure sharing focuses primarily on economic considerations and competitive implications [25]. Notably, existing legislation and regulatory frameworks [26] governing infrastructure sharing emphasize economic efficiency and environmental sustainability, yet largely neglect the network resilience.

Concerning equipment diversity in mobile networks, significant information asymmetries exist. Equipment specifications and deployment details are typically classified as proprietary and not disclosed publicly. Consequently, no readily accessible dataset exists to support empirical studies on equipment diversity at scale. Existing literature on equipment-related topics focuses narrowly on cybersecurity aspects [27]. Regulatory agencies in Europe and North America similarly restrict their focus to equipment security through national security frameworks [28] [29], emphasizing equipment vendor restrictions based on perceived national security risks. However, current regulatory approaches do not address the relationship between equipment diversity and network resilience.

IV. Data Collection

For our study, we conducted a comprehensive search for data on mobile installations across Europe. We identified several official sources published by national administrations and regulators in various countries.

We identified available data for Belgium [30], Denmark [31], France [32], Germany [33] and Switzerland [34]. After careful comparative evaluation, we selected French data and data from the Walloon Region of Belgium as the basis for our analysis. This selection is motivated by several key factors:

France provides a complete and consistent historical record of mobile installations since 2018, with data formats that enable precise identification of shared antennas. While Danish data was available, it proved insufficiently detailed for our purposes, particularly regarding the identification of shared antennas.

Regarding Germany and Switzerland, their complex federal structures make it particularly challenging to access detailed data on mobile installations, as this information is distributed across multiple regional entities. Moreover, the quality and format of the data can differ significantly from one entity to another. Nevertheless, we retained Belgian data despite its similar federal structure, because the Walloon information demonstrated exceptional quality: data consistency, high level of detail, and crucially, the ability to identify antenna manufacturers and models. Although we couldn't obtain equivalent data for the Flemish and Brussels Regions, this Walloon source proved particularly valuable for enhancing our analysis.

To complement this infrastructure data, we also used French municipal population density figures [35] to characterize the deployment context of each antenna installation. Each antenna was assigned the population density of the municipality in which it is located, enabling a spatial analysis of sharing practices as a function of population density.

V. Methodology

We downloaded the French data from the National Frequency Agency (ANFR), which provides a comprehensive dataset of all sites in the country. This dataset includes information about the location of each site, the antennas installed, and the operators using these antennas. We also obtained historical data to analyze the evolution of antenna sharing over time. Using this data, we were able to retrieve installations covering the period from March 2018 to February 2026.

We then applied several filters to this data: First, we filtered the antennas to retain only those used by GSM, UMTS, LTE, and 5G mobile networks, thereby excluding antennas not linked to mobile networks such as Radio or TV broadcast antennas. Next, we decided to exclude overseas territories, as this study focuses on a national-scale analysis. The antennas in these territories, along with their local specificities (particularly the large number of local operators), would not be visible in the overall data and would require separate analysis if they were to be considered. Finally, we excluded all installations not belonging to one of the four historical French operators (Orange, SFR, Free, Bouygues Telecom). Indeed, certain installations linked to specific and private uses from other entities, such as the National Railway Company (SNCF) or military archives service, generated noise in the data, without being relevant due to their small number (SNCF: 8309 antennas in 2026).

In Belgium, there is no centralized database of mobile antennas. Instead, the regulator legally requires and publishes individual installation reports for each antenna site and each operator separately. To obtain a complete picture of all operators' antennas, we therefore had to aggregate these per-site, per-operator reports.

Due to the lack of a centralized database, we chose to focus solely on installations located in the Walloon region, as they provided the most consistent information, even though they only allowed us to obtain data at a single point in time, without historical records.

We therefore collected the positions of sites and the operators present using the Walloon Registry of Stationary Emitting Antennas. Through this same registry [30], we were able to obtain links to the regulatory-mandated installation reports on the sites. These reports are not self-submitted by operators but are legally required under Belgian electromagnetic radiation protection laws [36]. These reports provide detailed information about the operators' antennas, including manufacturer and antenna model, which offered greater specificity than typically available in other datasets. To build our analysis, we collected all the reports for active sites in October 2025, extracted the antenna data, and aggregated them into a single dataset.

In the following analysis, we examine antennas shared among multiple operators. In France, each antenna has a unique identifier and is linked to an operator via this identifier, making it straightforward to identify shared antennas when the same identifier appears for multiple operators. The Belgian context required a different approach. We defined a shared antenna as one where, for the same site, multiple operators report in their installation records an antenna with identical characteristics in terms of height, azimuth, manufacturer, and model. We validated this definition by manually cross-checking a sample of antennas against site photographs and architects' drawings, and by seeking confirmation from the regulatory authority that issued the installation reports, which endorsed our interpretation.

VI. Analysis

We now analyze the collected data, starting with the evolution of sites sharing, then antenna sharing in France. Finally, we examine the diversity of hardware used in Belgium.

A. Shared sites

As of 2026, 50.71% of radio sites in France are shared by two or more operators. This can therefore be considered a common practice. However, this practice reduces geographic diversity and may pose a risk to the resilience of communications relying on multiple operators. Indeed, it concentrates transmission sites, which can lead to similar network coverage. Additionally, it presents a risk in case of hardware failure, as all transmission equipment is concentrated in a single location.

TABLE I
Number of sites in France, categorized by mobile network operators involved in the sharing.

Operator Association	Sites	2018-08 % Total	Sites	2026-01 % Total
O	12186	26.50	13018	19.10
F	4841	10.53	10702	15.71
B + O + S + F	4787	10.41	10567	15.51
B + S	5366	11.67	8030	11.78
B	3548	7.72	5413	7.94
S	3728	8.11	4458	6.54
B + S + F	2985	6.49	4434	6.51
O + F	1866	4.06	4459	6.54
B + O + S	2389	5.20	2612	3.83
O + S	1167	2.54	939	1.38
B + F	809	1.76	1113	1.63
S + F	575	1.25	835	1.23
B + O	701	1.52	630	0.92
O + S + F	609	1.32	511	0.75
B + O + F	424	0.92	419	0.61

B = Bouygues Telecom **F** = Free **O** = Orange **S** = SFR

By examining the various operator associations at shared sites, their quantities, and the proportion of total sites they represent in 2018 and 2026 (Table I), we observe that the number of sites shared by all four operators has more than doubled. However, this only represents approximately a 5% increase in the overall share of sites. This is explained by the substantial growth of the total number of sites over the same period, which increased by 22,159 sites (+48.19%).

Comparing these figures with those of sites exclusively operated by either Orange or Free reveals two distinct trends. Orange, which held the largest share of sites in 2018 with 12,186 installations (26.50% of the total), maintains its dominant position but sees its proportion decrease to 19.10%, despite growth in its number of sites ($< 1,000$). Conversely, Free, which had only 4,841 sites in 2018, experienced significant growth, reaching 10,702 sites and gaining 5% in overall share. This divergence can be explained by Orange's already extensive network, while Free needed to densify its installations to expand coverage. This dynamic also explains why Orange's overall share is decreasing, as its existing sites now host new operators.

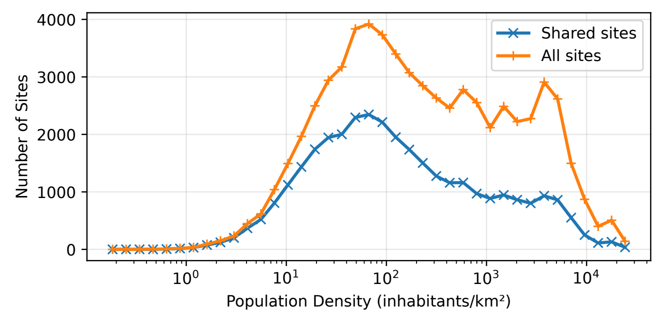

Fig. 2. Distribution of shared and total sites by population density in France in January 2026.

To complement this temporal analysis, we also examine how site sharing varies spatially with population density. Figure 2 shows the distribution of shared and total sites as a function of population density in January 2026. In low-density areas, up to approximately 100 inhabitants/km², the two distributions remain close, suggesting that a large share of installations in sparsely populated and peri-urban zones tend to be shared. This concentration is likely reinforced by regulatory obligations requiring operators to extend coverage in underserved rural areas [37]. Beyond this threshold, the gap between the two distributions widens more markedly, as the proportion of shared sites decreases while the total number of sites remains substantial, consistent with operators deploying additional dedicated infrastructure to meet higher demand in denser areas. From a resilience standpoint, this observation suggests that M2M applications relying on multiple operators in rural or peri-urban zones may benefit less from operator diversity than similar deployments in urban environments.

Despite the lack of historical data, an analysis of sites in Wallonia reveals that 60% of sites are shared (Table II). In both regions, shared sites outnumber those operated by a single operator, though the proportion is somewhat higher in Wallonia. The structural differences between the two countries, including the number of operators, the regulatory framework, and historical deployment patterns, make a direct causal comparison difficult.

TABLE II
NUMBER OF SITES IN WALLONIA, CATEGORIZED BY MOBILE NETWORK OPERATORS INVOLVED IN THE SHARING IN OCTOBER 2025.

Operator Association	Sites	% Total
ORANGE + PROXIMUS	885	33.92
ORANGE + PROXIMUS + TELENET GROUP	571	21.89
TELENET GROUP	569	21.81
PROXIMUS	234	8.97
ORANGE	224	8.59
ORANGE + TELENET GROUP	76	2.91
PROXIMUS + TELENET GROUP	50	1.92

In France, the observed dynamics suggest that shared sites may become more prevalent over time. Indeed, we have observed that when a dominant operator achieves sufficiently dense territorial coverage, the number of its sites begins to stagnate. It may then be led to host new operators on its sites, whether for economic reasons (to maximize return on investment) or administrative reasons (difficulty in creating new installations). However, we note that this phenomenon occurs in a specific case: here, a fast-growing operator, Free, invests massively in new installations, thereby rapidly increasing the number of these installations.

B. Shared antennas

We have seen that sites can be shared among multiple operators and that this practice is increasing. However, today, sites are no longer the only shareable component; radio access networks (RAN) can also be shared, either by pooling frequencies between operators or without doing so. Given that we could not ascertain if frequencies were pooled, our discussion will be confined to antenna sharing.

Sharing antennas with another operator reduces network operating costs, but it raises more concerns about network resilience compared to sites sharing. This added shared equipment among multiple operators increases the risk of a failure simultaneously impacting several mobile networks.

We will now analyze how the number of shared antennas has evolved over the years and their share in the total number of antennas. We will then examine whether this evolution follows different trends depending on the technology used. Finally, we will look at the various operator sharing associations.

Figure 4 shows both the percentage of shared antennas and the total antenna count evolution. It shows the proportion of shared antennas and reveals an interesting pattern. While the total number of antennas remained stable until 2021, the share of shared antennas steadily increased to reach 19% of the total. This trend temporarily reversed when the total number of antennas began growing again, causing the share to drop to 16%. However, from 2022 onward, the share of shared antennas continued its consistent growth to reach 20% of the total in 2026.

Continuing our analysis with Figure 3, which shows the total number of antennas and the number of shared antennas by technology, we note that the total counts per technology exceed those in Figure 4 because an antenna supporting multiple technologies is counted once per technology in Figure 3, whereas it is counted only once overall in Figure 4. We observe that the decline in the overall percentage of shared antennas in 2021 can be attributed to the deployment of 5G antennas. Indeed, the number of 5G antennas experienced significant growth in 2021, while the number of shared 5G antennas only began to increase later that year. Before 2021, the number of shared 5G antennas was zero, suggesting that operators were initially reluctant to share this new technology. However, once this initial phase passed, we see a rapid increase in shared 5G antennas, likely to reduce costs or improve competitiveness.

For other technologies, no such strong growth is observed. This may be because they are not new. The number of LTE antennas continues to grow slightly, as does the number of shared LTE antennas. Meanwhile, UMTS antennas, an older technology, are entering a decommissioning phase, with a sharp decline in their numbers by 2026 [38] [39] [40] [41]. However, this decline does not affect shared UMTS antennas, as some operators likely prefer to maintain service at a lower cost by using shared antennas. This could pose resilience issues for equipment still relying on this technology, such as certain vehicle fleets [42] [43].

The GSM network is also being decommissioned [38] [39] [40] [41], but it appears that, unlike UMTS, the number of shared antennas seems to be stagnating. This can be explained by the fact that GSM is older and that operators may have already reduced the number of antennas before focusing on UMTS. Additionally, GSM is still used for certain critical services, such as emergency calls [44] [45], which could explain why operators have maintained a certain number of GSM antennas in service.

TABLE III
NUMBER OF ANTENNAS IN FRANCE, CATEGORIZED BY MOBILE NETWORK OPERATORS INVOLVED IN THE SHARING

Operator Association	2018-08 Antennas		2026-01 Antennas	
	Antennas	% Total	Antennas	% Total
O	78317	35.14	117046	29.87
F	47333	21.24	103850	26.50
B + S	31900	14.31	60042	15.32
B	33719	15.13	48848	12.47
S	31358	14.07	43489	11.10
B + O + S + F	107	0.05	17435	4.45
B + O + S	6	0.00	488	0.12
O + S	25	0.01	205	0.05
O + S + F	18	0.01	111	0.03
B + O + F	11	0.00	113	0.03
B + O	18	0.01	93	0.02
B + S + F	12	0.01	74	0.02
O + F	26	0.01	54	0.01
B + F	24	0.01	18	0.00
S + F	8	0.00	7	0.00

B = Bouygues Telecom **F** = Free **O** = Orange **S** = SFR

When examining the number of antennas by operator association (Table III), we observe that Orange and Free are the leaders in terms of antenna count, following trends similar to those of sites. Orange continues to grow, but at a slower pace than Free, thus losing share of the total antennas, while

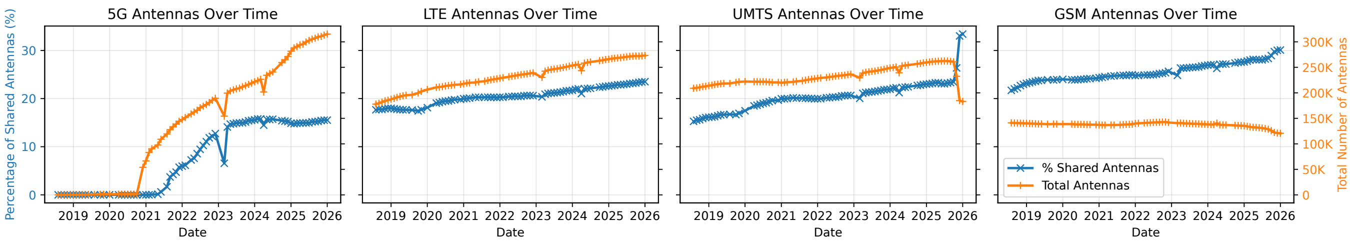

Fig. 3. Comparison of the total number of antennas and the number of shared antennas for different technologies from 2018 to 2026 in France.

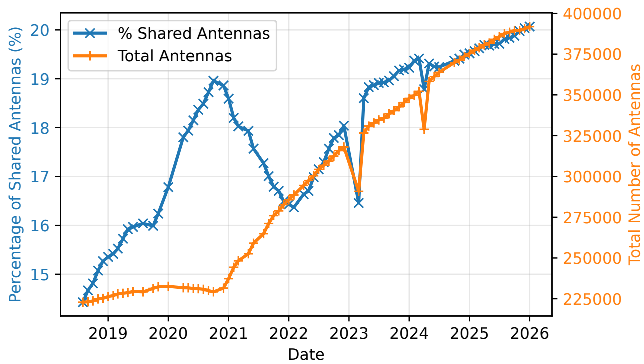

Fig. 4. Evolution of the percentage of shared antennas associated with the total number of antennas in France.

Free gains share through a significant increase in its number of antennas.

What is particularly interesting is that in third place, we do not find a single operator, but rather the association of two operators: Bouygues Telecom and SFR. This position is explained by an agreement between these two operators to share their networks and thus remain competitive. It is notable that these antennas shared by the two operators already represented half of each operator's antennas in 2018. In 2026, this figure has increased further and now represents 55% of their antennas, raising questions about the interdependence of these two operators' infrastructure.

Finally, what surprised us the most was finding that some antennas are shared by all four operators. Although this number was negligible in 2018 with only 107 shared antennas, this figure exploded in 2026 to reach 17,435, or 4.45% of the total number of antennas. This is particularly concerning as this number is substantial and represents a real worry regarding the resilience capacity of mobile networks in areas where these antennas are deployed. This statistic clearly needs to be monitored to see how it will evolve in the future.

This analysis reveals that, in France, antenna sharing has become a significant strategy, representing 20% of all antennas in 2026, while introducing compromises in terms of resilience and operator governance over mobile infrastructure.

From a technological perspective, we observed that even when a new technology like 5G enters the market, its antennas are not immediately shared among operators but only at a later stage. Regarding older technologies, during their decommissioning phase, shared antennas do not appear to follow the same decommissioning trend as non-shared antennas. Rather than decreasing, the number of shared antennas stagnates, while the number of non-shared antennas declines, suggesting that operators tend to retain shared infrastructure longer before decommissioning it.

With regard to different operator associations, the increasing number of antennas shared by all four operators is particularly concerning and raises significant questions about their resilience capabilities.

The Bouygues-SFR partnership further illustrates how sharing can reshape competitive dynamics, raising questions about long-term interdependence.

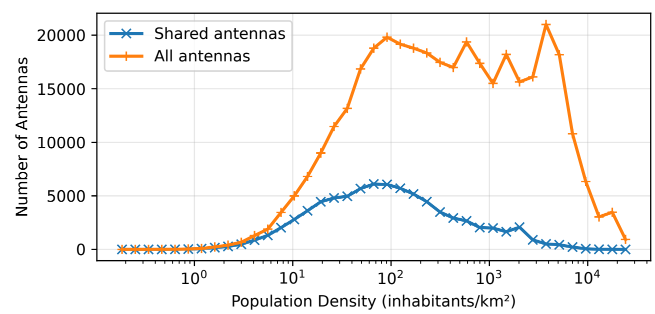

Fig. 5. Distribution of shared and total antennas by population density in France in January 2026.

The spatial distribution of shared antennas in January 2026, presented in Figure 5, provides additional insights into the pattern already observed for sites in Figure 2. Both distributions diverge early, around 10 inhabitants/km², after which the total number of antennas grows substantially while the number of shared antennas increases more moderately, peaking around 100 inhabitants/km² before decreasing steadily. Above 10^4 inhabitants/km², shared antennas become marginal, while the total number of antennas remains substantial. Antenna sharing is concentrated in moderate-density areas, while dense urban deployments rely mainly on dedicated per-operator infrastructure, a trend more pronounced here than for sites. This observation reinforces the idea that resilience considerations are particularly relevant for M2M deployments operating outside dense urban areas.

TABLE IV
NUMBER OF ANTENNAS IN WALLONIA, CATEGORIZED BY MOBILE NETWORK OPERATORS INVOLVED IN THE SHARING IN OCTOBER 2025.

Operator Association	Antennas	% Total
TELENET GROUP	1245	31.73
PROXIMUS	1189	30.30
ORANGE	1060	27.01
ORANGE + PROXIMUS	430	10.96

In Wallonia, our analysis of shared antennas (Table IV) reveals that antenna sharing is less prevalent than in France, with only 10% of antennas shared between Orange and Proximus. Nevertheless, this represents a significant 35% of each operator's antenna infrastructure, which is not insignificant. We will examine the antenna model used in more detail later in our analysis to understand how shared antennas integrate with each operator's proprietary equipment.

C. Hardware diversity

Antenna sharing is not a phenomenon limited to France. As shown in Section VI-B, in Wallonia, Belgium, Proximus and Orange share 35% of their antennas. In France, we had no information about which antenna models were used by the operators. However, in Wallonia, the antenna installation reports allowed us to precisely identify the antenna models used by different operators. Based on this new information, we will now focus on analyzing the hardware used by operators in Wallonia and examine whether this equipment is sufficiently diversified in terms of manufacturer diversity to avoid representing a risk in case of security vulnerability or firmware failure. Our analysis will proceed in three distinct stages. We will begin by examining the distribution of antenna manufacturers across different frequency bands in the Walloon inventory. Next, we will analyze the presence of various manufacturers within each operator's network. Finally, we will conduct a detailed study of the specific antenna models used by the most prominent manufacturers.

Figure 7 shows the proportion of equipment from each manufacturer for each frequency band used by mobile operators in Wallonia, using the standard notation introduced in the 5G NR specification [46]. For frequency bands below 3000 MHz, Commscope and Huawei equipment dominate, with Huawei generally accounting for over 50% of the equipment in these bands.

For bands above 3000 MHz, such as n78, the situation changes: Nokia and Ericsson equipment are predominantly used, with Nokia representing over 60% of the antennas operating in this band.

This difference in manufacturers for the n78 band can be explained by several factors. First, this band was introduced with 5G technology [46], an area where Nokia and Ericsson are key players with a large number of patents [47]. Additionally, these manufacturers likely benefited from Western countries' reluctance to use Huawei equipment for advanced technologies like 5G due to security and espionage concerns [28] [29].

The dominance of certain manufacturers is concerning and raises serious questions about dependence and resilience. However, simply observing which manufacturers are used across frequency bands is insufficient. We must also examine manufacturer distribution by operator.

Examining the number of antennas by manufacturer for different Walloon operators on Figure 6 reveals distinct strategies. Orange and Proximus maintain a relative balance between Huawei and Commscope equipment. Telenet, however, demonstrates a more concentrated approach, with heavy reliance on Huawei and three main manufacturers: Huawei, Kathrein, and Ericsson. The divergence becomes particularly evident in 5G equipment choices. While Orange and Proximus selected Nokia solutions, Telenet opted for Ericsson. This latter choice likely stems from Kathrein's 2019 acquisition by Ericsson [48], suggesting an ecosystem-based rationale.

These findings are partially reassuring: while operators like Telenet have highly concentrated antenna inventories around a few manufacturers, other operators, such as Orange and Proximus, appear to maintain a greater diversity of equipment in their infrastructure. However, it is interesting to note that despite this apparent diversity, Orange and Proximus appear to have very similar inventories, both for shared antennas and their own equipment. This similarity becomes even more apparent when examining the specific models used by each operator in detail in Table V.

TABLE V
FOCUS ON THE ANTENNA MODELS USED BY HUAWEI, COMMSCOPE, NOKIA, AND ERICSSON FOR EACH OPERATOR IN WALLONIA.

OPERATEUR Manufacturer Reference	Orange	Orange Proximus	Proximus	Telenet Group
Huawei				
AQU4519R1v06	0	0	0	303
ASI4519R2v06	0	0	0	302
A06240PA04v06	117	62	116	0
AOC4518R0v06	113	54	111	0
ATR4518R12	10	0	12	131
Other	134	52	256	221
Commscope				
RRZZV4-65D-R8N43	220	103	204	0
EGRZV4-65D-R8N43	63	25	60	0
RRZZHHTT-65B-R7N43	54	25	49	0
EGRZZHHTT-65B-R8N43	24	8	27	0
CS7801002	22	6	23	0
Other	33	5	32	0
Nokia				
AQQQ	70	20	116	0
PFAB	13	8	15	0
PFAA	5	4	6	0
Other	5	0	17	0
Ericsson				
AIR3278-B78K	0	0	0	31
AIR3227	0	0	0	27
KRE1012475	0	0	0	13
Other	0	0	0	7
Other	421	58	250	226

The detailed model analysis reveals a striking convergence between Orange and Proximus: both operators predominantly use the same equipment references, whether for Commscope

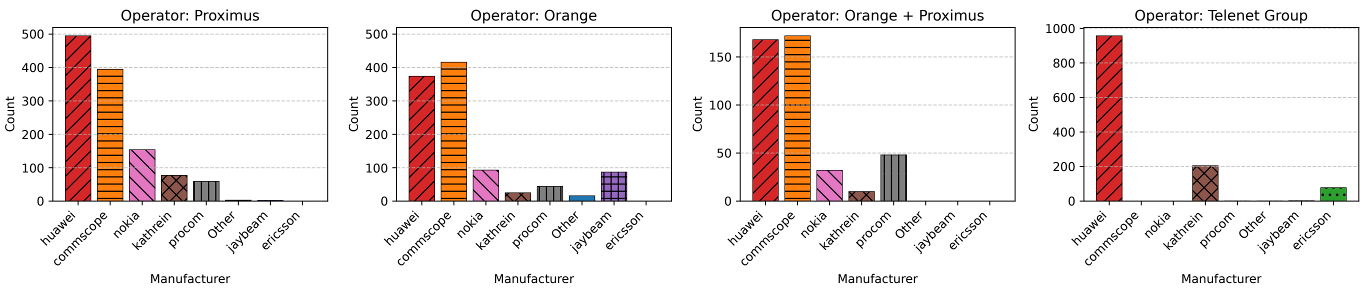

Fig. 6. Number of antennas by manufacturer for each operator in Wallonia.

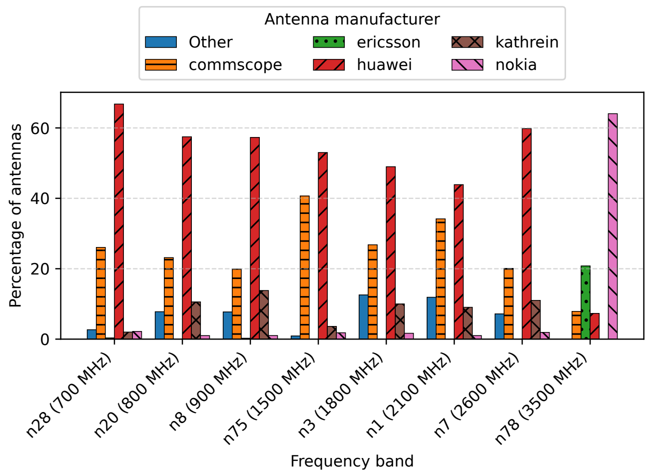

Fig. 7. Proportion of antennas by manufacturer for each telecom band in Wallonia.

or Huawei antennas. While Telenet also has a significant number of Huawei devices, its model choices differ from those of Orange and Proximus. For advanced 5G equipment (Nokia and Ericsson), the concentration is even more pronounced, with only one or two major references used per operator.

This standardization of models, particularly between Orange and Proximus, exacerbates the market's dependence on specific manufacturers. While this uniformity might seem insignificant for basic antennas, it becomes concerning for intelligent antennas like Nokia's. Should a security vulnerability [49] [50] be discovered in these specific models or in case of firmware failure, the consequences could be systemic for the entire Walloon network.

VII. Discussion

Our analysis of France and Wallonia has shown that infrastructure sharing, particularly for antennas, is a significant and growing practice in these regions. However, this mutualization raises important questions about the resilience of mobile networks. Although our data did not allow us to clearly identify the exact sharing configurations, it is highly likely that this mutualization extends beyond just antennas to include transmission equipment as well.

It is worth noting that infrastructure sharing is not inherently detrimental to resilience. Sharing can play a positive role in specific contexts, such as the coverage of geographically complex areas or the continued operation of legacy technologies, where it enables operators to maintain service at lower cost, and can even improve redundancy by increasing coverage overlap in areas that would otherwise be poorly served. However, when sharing extends to a significant portion of operators' infrastructure, as our analysis reveals, the risk of correlated failures increases, particularly for applications relying on multipath communications to achieve resilience.

With current infrastructure sharing, the use of multipath technologies for critical applications may be less effective if the selected operators have chosen sharing agreements with each other, as the resilience gains will be limited. To maximize resilience in multipath deployments, it is essential to select operators that maintain independent infrastructure. When two or more operators share a significant portion of their infrastructure, selecting only operators within such partnerships provides limited resilience benefits. Deployments seeking to achieve optimal resilience should include at least one operator outside of any existing sharing agreements. Operators that maintain minimal infrastructure sharing with each other, or that operate outside established partnership pools, are stronger candidates for achieving diverse and independent communication paths. It therefore seems essential to take into account the infrastructure-sharing agreements established in the deployment area of an application using multipath communications.

Regarding equipment diversity, while our detailed data is limited to Wallonia, we have observed a strong concentration of equipment around just a few manufacturers and models. Although defining a precise threshold for what constitutes "sufficient" diversification is beyond the scope of this paper, our analysis flags the risk: if two operators share the same antenna model (as Orange and Proximus do for most of their inventory), a single firmware vulnerability or hardware defect could affect both simultaneously. The practical implication for MNO selection is to prefer, where possible, operator pairs whose equipment inventories are known to differ.

Diversifying equipment, whether within a single operator or among operators sharing antennas, could be a solution to reduce these risks. However, this approach could also lead to increased costs by limiting economies of scale and complicate network management by introducing greater variety of equipment to maintain.

It therefore appears essential to find an optimal balance between operational simplicity and resilience, to ensure that mobile networks remain sufficiently robust to withstand potential failures or attacks. Currently, regulators focus primarily on competition and coverage aspects, but it would be advisable for them to also incorporate resilience considerations into their regulatory approaches regarding infrastructure sharing.

VIII. Future Work

A valuable extension of this work would involve examining how infrastructure sharing impacts network coverage. Sharing can enhance redundancy through coverage overlap, but may simultaneously increase correlated-failure risk; disentangling these two effects requires combining detailed geographic analysis with simulation models. Such a methodology would not only identify areas where sharing has the greatest impact on diversity, but also assess whether the coverage benefit of shared antennas compensates for the loss of infrastructure diversity in those zones.

The use of simulation models would additionally provide the opportunity to test various infrastructure sharing scenarios. These simulations would enable quantitative assessment of how different sharing configurations impact overall network performance, particularly in critical situations such as technical failures or targeted attacks on shared infrastructure. This modeling approach could reveal unsuspected vulnerabilities and suggest optimal configurations to reconcile economic efficiency with network robustness.

Another promising direction would be to incorporate tower ownership data into the analysis. In many countries, physical masts are not owned by the operators themselves but by specialized infrastructure companies, known as Tower Companies (TowerCos), which lease access to multiple operators simultaneously. This model is a structural driver of co-location: operators independently deploy their antennas on the same mast without any explicit sharing agreement between them. In France, for instance, ANFR publishes tower ownership data, making it possible to quantify the TowerCo footprint and its contribution to the sharing patterns we observe. Incorporating such data could enable a more precise characterization of shared infrastructure risk, and potentially support the development of a broader methodology for detecting shared RAN segments beyond the antenna level.

IX. Conclusion

In this study, we analyzed the evolution of infrastructure sharing in mobile networks in France and examined the equipment used in Wallonia, Belgium. In France, we found that radio-site sharing is a common practice, with over 50% of sites shared by multiple operators in 2026, up from 47% in 2018. Antenna sharing, although less widespread, has grown steadily and now accounts for about 20% of all antennas in France. This pooling raises significant concerns about the resilience of mobile networks in France, especially in the event of failures or vulnerabilities affecting shared equipment.

In Wallonia, an analysis of equipment diversity revealed a strong concentration around a few manufacturers and models, increasing dependency risks. It is crucial to strike an optimal balance between operational simplicity and resilience to ensure the robustness of mobile networks against emerging uses such as multipath communications, which, in an overly concentrated shared infrastructure environment, would lose efficiency and relevance, no longer delivering the expected resilience gains.

In conclusion, while our findings are scoped to France and Wallonia and may not generalize to other countries, they illustrate that accounting for infrastructure-sharing agreements is a necessary step when selecting operators for resilient multipath deployments, and that implementing equipment-diversification strategies is essential to mitigate concentration risks and ensure the long-term resilience of mobile networks.

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Appendix

Ethical Considerations

For our study, we used publicly accessible data. There is no personally identifiable information in that data. To avoid overloading website servers, we intentionally limited the frequency of our data queries. Furthermore, we did not conduct active measurements on operator networks, thereby avoiding any potential impact on network traffic and users.