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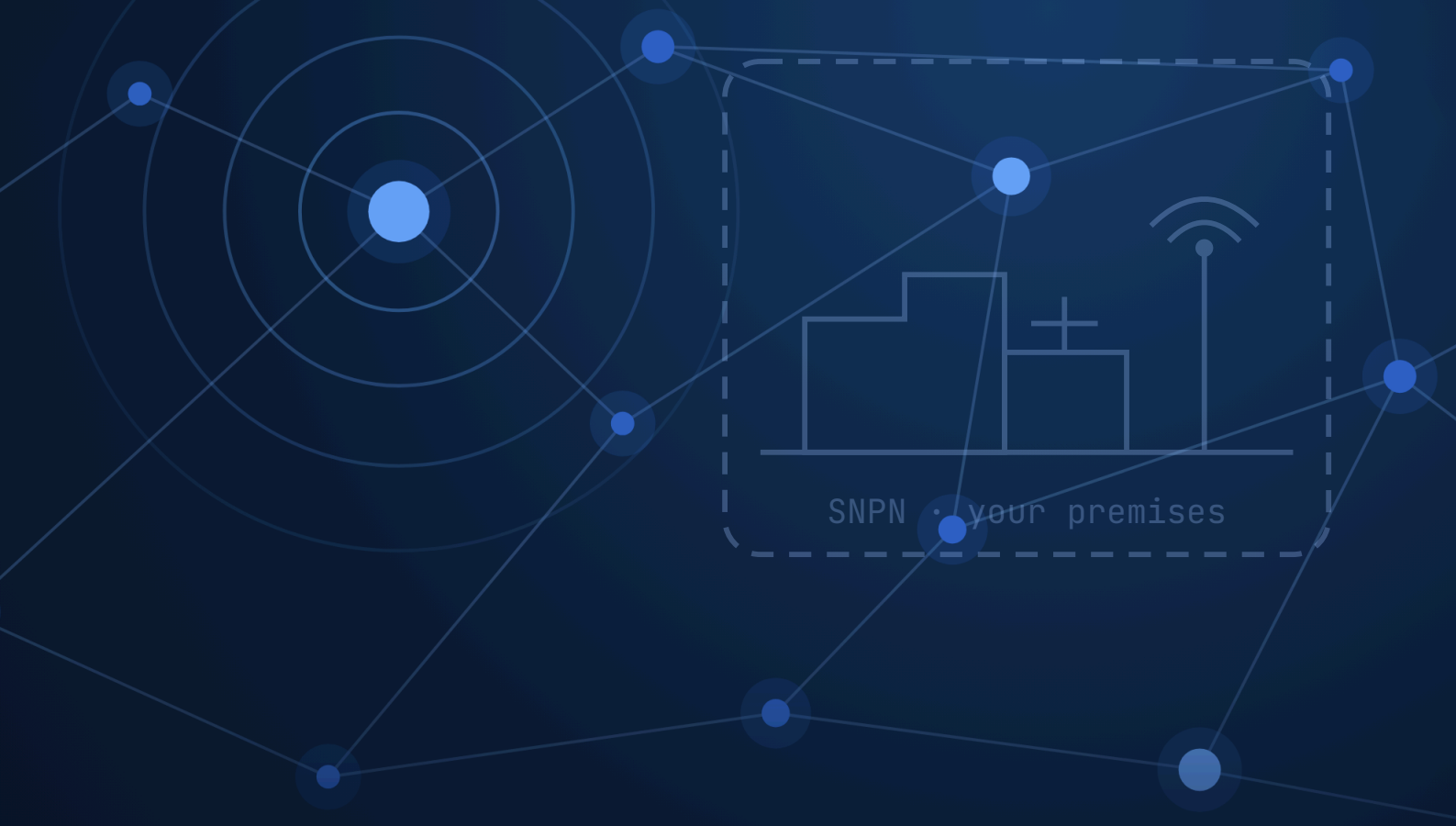

TECHNICAL WHITEPAPER

Private 5G: A Deployment Guide

What it takes to put a 5G network inside a factory in 2026: the SNPN and PNI-NPN models in plain terms, six countries' spectrum rules side by side, the market numbers with their definitions attached, and a checklist that starts where the brochures stop.

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***Abstract*—Private 5G had a strange 2025: AWS and Microsoft both retired their private-5G products, Nokia — the segment's largest vendor — moved to divest its integration unit, and yet deployments grew by roughly a third, to 6,500 networks worldwide by Berg Insight's count. The money, it turns out, is in radios, spectrum and integration, not in cloud subscriptions. This guide gives a working engineer what the brochures leave out: the two 3GPP network models (SNPN and PNI-NPN) and why the choice drives everything downstream; how a factory-fresh device gets onboarded under Rel-17; six countries' spectrum regimes with their actual fees and license counts; the 2026 market data with definitions attached; and a three-way architecture comparison with the 2025 exits marked as cautions. Costs are discussed honestly: no analyst-grade per-site figures exist, and we say so rather than inventing them.**

1. Introduction

In May 2025, Amazon listed AWS Private 5G among its discontinued services. Four months later, Microsoft retired Azure Private 5G Core and pointed its customers at Nokia and Ericsson partner offers in its own marketplace [20], [21]. In November, Nokia — ranked the segment's largest vendor, with roughly 960 customers — announced it would divest the unit that does private-5G integration [22], [2]. If you only read those three headlines, you would conclude the market was dying.

The deployment data says the opposite. Berg Insight counted 6,500 private LTE/5G networks in operation at the end of 2025, up from 4,700 a year earlier, and values the market at $2.4 billion on its way to a forecast $12 billion by 2030 [2]. GSA's tracker, which counts referenceable customers with contracts above €100,000, reached 1,953 organisations across 84 countries — a number that has compounded at 51% annually since 2017 [1]. Both things are true at once: enterprises are building these networks faster than ever, and the companies that tried to sell private 5G as a cloud subscription found no margin in it. This is an engineering market, not a platform market — which is good news if you are the engineer.

This guide covers what we would want to know before signing anything: the two 3GPP network models and their consequences (§2), the spectrum rules in six countries (§3), the market numbers worth trusting (§4), the three architecture paths (§5), and a deployment checklist with the honest unknowns left visible (§6).

2. Two Models, Not One Product

3GPP does not define "private 5G." It defines non-public networks (NPNs), in two flavors, in TS 23.501 clause 5.30 [18], [19] — and which one you pick decides your spectrum, your SIMs, and your relationship with operators before a single radio is mounted.

A **Stand-alone Non-Public Network (SNPN)** runs without any public operator: your RAN, your core, your subscriber database. It identifies itself with a PLMN ID plus a Network Identifier (NID), and PLMN codes from the non-unique range can be used — your factory does not need a national operator code to exist [19]. A **Public-Network-Integrated NPN (PNI-NPN)** is the opposite bargain: the network is delivered with a PLMN's support, typically as a slice or a set of dedicated cells, and the operator stays in your control plane.

PNI-NPNs come with an access-control tool worth understanding: the **Closed Access Group (CAG)**, introduced in Rel-16. 3GPP's own rationale is refreshingly blunt — network slicing cannot prevent an unauthorized phone from *attempting* to register in an area where its slice isn't offered; only cell-level access control can. A CAG marks cells as members-only: the AMF gives the RAN each device's allowed-CAG list, and everyone else's registration attempts are turned away at the cell [18]. Slices allocate; CAGs exclude.

The practical breakthrough for SNPNs arrived in Rel-17 under the "eNPN" work: **onboarding and remote provisioning**. A factory-fresh device with nothing but default credentials can attach to an Onboarding Network, be authenticated against a Default Credentials Server, and have its real SNPN subscription pushed to it by a Provisioning Server — after which it re-registers as a full member (Fig. 1). Rel-17 also allows the credentials to live with a separate **Credentials Holder**, and brings IMS voice and emergency calling into SNPNs [17], [18]. Together these closed the "how do a thousand sensors get SIM profiles" gap that made early SNPNs painful.

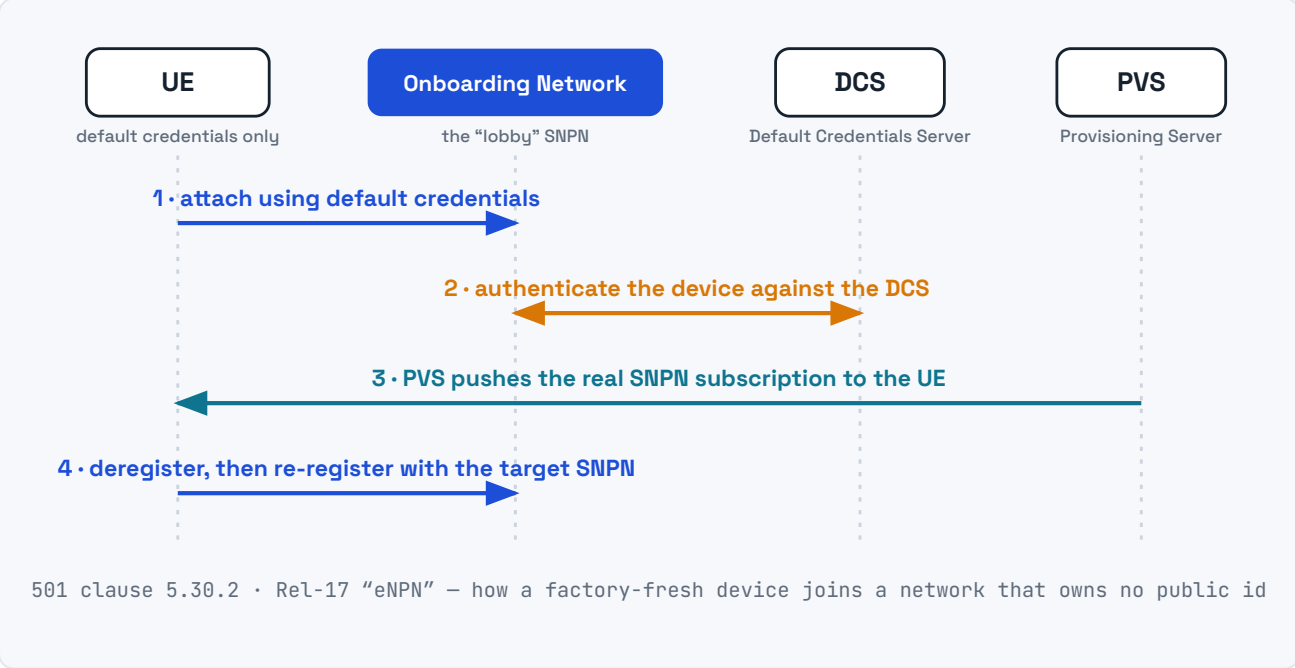

Fig. 1. Rel-17 SNPN onboarding: from default credentials to full network member in four steps. The Credentials Holder option means the authenticating entity need not be the network itself — a fleet owner or service company can hold the keys. Per 3GPP TS 23.501 cl. 5.30.2 [17]–[19].

3. Spectrum: Same Physics, Six Rulebooks

Nothing shapes a country's private-5G market like its spectrum policy. The radio engineering is identical everywhere; the paperwork is not (Table 1).

TABLE 1 · Six spectrum regimes for the same factory

Country	Band(s)	Model	Indicative fee	Scale (as of)
Germany	3.7–3.8 GHz (+ 26 GHz)	local license, applicant-defined area	€1,000 + B·t·5·(6a1+a2) — a published formula [4]	424 assignments, Oct 2024 (official); ~465 by spring 2025 per trade press [5], [25]
United States	CBRS 3.55–3.7 GHz	three-tier sharing under SAS (incumbents / PALs / GAA)	GAA: no license fee — registered by rule [6]	≈420,000 CBSDs on air, Aug 2025 (reported) [7]
United Kingdom	3.8–4.2 GHz (+ 1800/2300 MHz, 26 GHz)	Ofcom Shared Access license	£80 per 10 MHz/yr rural; urban medium-power tier from Oct 2025 [8], [9]	licenses listed in Ofcom's portal; no headline count published
Japan	4.6–4.9 GHz + 28.2–29.1 GHz	"local 5G" license per base-station plan	per Radio Act licensing [10]	153 licensees at 4.7 GHz vs 25 at 28 GHz, Dec 2024 (reported) [11]
France	3.8–4.2 GHz (+ 2.6 GHz TDD)	trials since Mar 2022 → permanent regime approved Dec 12, 2025	one-stop licensing window opening [12], [13]	175 trial licenses issued; ~90 active, Jun 2025 [14]
India	n78 / n79 / n257 (candidates)	CNPN authorisation rules finalized early 2026 — **direct spectrum assignment still unresolved**	no authorisation fee; spectrum path undecided [15], [16]	one enterprise (Adani) holds private-use spectrum, via the 2022 auction [15]

Germany made it a formula. BNetzA assigns local licenses in 3.7–3.8 GHz over an area you draw yourself, priced by a published equation — €1,000 plus a term scaling with bandwidth, years, and area [4]. The official monitoring report counted 424 assignments by October 2024, up 23% year-on-year; trade press put the figure around 465 by spring 2025 [5], [25]. **The United States** went the other way: no local licenses at all, but a 150 MHz commons at 3.55–3.7 GHz (CBRS) shared through automated Spectrum Access Systems across three tiers — federal incumbents, county-auctioned Priority Access Licenses, and free General Authorized Access [6]. Roughly 420,000 CBRS base stations were on air by August 2025 [7]; note that the FCC had an open proceeding on the band's rules as of mid-2026, so check the current state before designing around GAA. **The UK** sells Shared Access licenses for £80 per 10 MHz per year in rural areas of 3.8–4.2 GHz, with a pricier urban tier introduced in October 2025 [8], [9].

Japan licenses "local 5G" per base-station plan in 4.6–4.9 GHz and 28 GHz — and its experience is a warning about millimeter wave: 153 licensees chose the mid-band against 25 at 28 GHz as of December 2024 [10], [11]. **France** took the scenic route — trial licenses in 3.8–4.0 GHz since March 2022, 175 issued — before adopting a permanent 3.8–4.2 GHz regime approved on December 12, 2025 [12]–[14]. And **India** is the cliffhanger: the regulator recommended direct spectrum assignment to enterprises in February 2025, a government demand survey followed, the operators' association formally opposed it, and the captive-network authorisation rules were finalized in early 2026 — but the spectrum question itself remained unresolved at the time of writing. Do not let anyone tell you India "now allows" private-5G spectrum; the framework exists, the airwaves are still in committee [15], [16].

4. The Market, With Definitions Attached

Two trackers dominate the market conversation, and they count different things — quote them together without definitions and you will be wrong by a factor of three. **GSA** counts organisations with referenceable private-network contracts above €100,000: 1,953 of them across 84 countries at end-2025, led by manufacturing, then education and research, then mining; the United States, Germany and the United Kingdom top the country table — exactly the three most permissive spectrum regimes in Table 1 [1]. **Berg Insight** counts deployed networks excluding proofs-of-concept: 6,500 at end-2025, a market worth $2.4 billion and forecast to reach $12 billion by 2030 at 38% annual growth [2], [3].

Two details deserve more attention than they get. First, by GSA's data the installed base is still about half LTE — 5G dominates new announcements, but the mature, cheaper 4G ecosystem keeps winning deals where extreme throughput isn't the point [1]. An honest guide says it plainly: sometimes private LTE is still the right answer. Second, the 2025 exits cluster entirely on one side of the market. AWS and Azure sold private 5G as a cloud SKU; both retired [20], [21]. Nokia's divestment moves integration to channel partners while it keeps selling the radios [22]. Nobody exited radios or spectrum services. Read as a map of where the money is, not whether it exists.

5. Three Ways to Build It

Architecture choices reduce to one question: which failures and obligations are you willing to own? Table 2 compares the three paths on the factors that actually decide projects.

TABLE 2 · Three ways to build it — and who carries which risk

Decision factor	Full on-prem (SNPN)	Hybrid / cloud-managed	Operator-integrated (PNI-NPN)
Data residency	everything stays on site	user plane on site; management plane in vendor cloud	negotiable — on-prem UPF possible, control in the PLMN
If the WAN fails	network keeps running	traffic survives; management/changes degraded	depends on what stayed on site
Latency path	shortest — all local	local user plane	local only with an on-prem UPF
SIMs / credentials	yours (or a Credentials Holder, Rel-17)	yours, cloud-orchestrated	the operator's
Opex model	capex-heavy, own ops team	subscription + small ops team	service contract
Named examples	Ericsson Private 5G, Nokia DAC, Samsung, Huawei, ZTE [23]	Celona "5G LAN"; HPE Athonet [2], [23]	operator slice / CAG-fenced cells — products vary by market
2025–26 caution	Nokia is divesting its private-5G integration unit; channel-led model ahead [22]	AWS and Azure both retired their private-5G products — pick partners whose core business this is [20], [21]	verify the operator's offer is productized, not a one-off project

The full on-prem SNPN maximizes sovereignty — data never leaves, the network survives a WAN cut, latency is whatever your switch fabric says it is — and in exchange you become a small telecom operator, with the staffing that implies. The hybrid path keeps the user plane local but moves orchestration to a vendor cloud; it is the easiest to run, and after 2025 the diligence question writes itself: is private networking this vendor's core business, or a side bet? The operator-integrated PNI-NPN trades autonomy for a service contract — entirely reasonable for campuses that already live inside good macro coverage, especially with CAG-fenced cells and an on-prem UPF; just confirm the offer is a product with a roadmap, not a one-off project wearing a product's name.

6. The Deployment Checklist

The sequence that works, in the order that avoids rework:

1. Spectrum first. Apply early — it gates everything. In Germany, compute your fee from the formula; in the US, decide GAA-now versus PAL-protection; in the UK, budget the urban tier if applicable; in India, track the assignment decision before promising dates [4]–[9], [15].

2. RF design before vendor selection. Mid-band carries the world's private networks for a reason — Japan's 153-to-25 split between 4.7 GHz and mmWave is the ecosystem voting with its licenses [11]. Treat 26/28 GHz as a special tool for dense, fixed, high-throughput zones, not the default.

3. Pick the architecture from Table 2, explicitly, in writing, with the failure modes acknowledged — "what happens when the WAN fails" is the question that separates real requirements from brochure requirements.

4. Decide the credential model. Own SIMs in an SNPN, a Rel-17 Credentials Holder if a fleet owner or service company should hold the keys, or operator SIMs in a PNI-NPN. If devices arrive in bulk, insist on Rel-17 onboarding support rather than a van full of pre-provisioned SIM cards [17].

5. Integrate with the OT network deliberately. The 5G system terminates at N6; the PLCs live on industrial Ethernet. Plan the routing, addressing and security boundary between them as its own workstream — it is where schedules actually slip.

6. Cost it honestly. No analyst-grade per-site cost ranges exist in public — we checked. Vendor and integrator blogs circulate figures from tens of thousands of dollars for a small site to over a million for multi-campus builds [24]; treat these as anecdotes that bound the conversation, not as market data. The structural drivers are radio count, core licensing model, and the integration share — which the single-vendor behavior documented in our Open RAN paper suggests is the line item everyone underestimates.

7. Conclusion

Private 5G in 2026 rewards the unglamorous reading. The 3GPP machinery is finished — SNPN and PNI-NPN are mature, Rel-17 solved onboarding, CAG solved access control. The gating factor is regulatory, and Table 1 is really a league table of regulatory courage: the three countries that made spectrum cheap and procedural lead every deployment ranking. The market is growing at nearly 40% while the platform tourists leave, which tells you the value sits with whoever does the engineering.

Watch four things over the next year: India's direct-assignment decision, which unlocks or defers the largest untapped enterprise market; the FCC's CBRS proceeding; whether Nokia's channel-led model holds its #1 position; and the BNetzA assignment count, the cleanest single indicator of industrial demand. Then pick your model, file for your spectrum, and build the thing — the paperwork is now harder than the physics.

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