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The Role of Neutral Host Models in Expanding the Adoption of Private Wireless Networks

Rahul Bangera

Ellicott City, MD, USA.
rahulmbangera@gmail.com

Abstract:
The telecommunications industry is currently experiencing a crucial transition driven by the integration of enterprise digitization, the limitations of traditional indoor connectivity solutions, and the expansion of radio spectrum. This research paper provides a comprehensive techno-economic and architectural analysis of Neutral Host Networks (NHNs) and their crucial role in accelerating the deployment of Private Wireless Networks (PWNs). The paper critically assesses the shift from traditional Distributed Antenna Systems (DAS) to advanced, virtualized architectures such as the Multi-Operator Core Network (MOCN). By thoroughly analyzing deployment data, Total Cost of Ownership (TCO) models, and spectral efficiency measures, this study shows that NHNs utilizing shared spectrum (notably CBRS) and small cell configurations provide a revolutionary alternative to older methods. The analysis is backed by real-world evidence from large deployments by Meta, Cummins, and the University of Virginia, demonstrating the operational efficiency of hybrid public-private network models. Additionally, we examine the impact of 3GPP Release 17 standards and Open RAN development. The findings indicate that the Neutral Host model is more than just a coverage extender; it is a key facilitator for the "middle enterprise" private 5G market, which is expected to create significant economic value by 2030.

Keywords: Neutral Host Networks (NHN), Private 5G, Citizens Broadband Radio Service (CBRS), Multi-Operator Core Network (MOCN), Distributed Antenna Systems (DAS), Techno-Economic Analysis, Indoor Coverage, Industry 4.0.

I. INTRODUCTION

A. The Indoor Connectivity Paradox

The widespread availability of cellular connectivity has shifted from being a convenience to a vital utility necessary for operational continuity in modern businesses. While Mobile Network Operators (MNOs) have heavily invested in macro-cellular infrastructure to provide extensive outdoor coverage, radio wave physics create a persistent "indoor connectivity paradox." Statistical data consistently show that about 80% of mobile data usage occurs indoors [1], yet the macro network's ability to penetrate modern building materials, especially Low-E glass and concrete, is decreasing. This problem worsens with the shift to 5G, which uses higher-frequency bands (C-band and mmWave) that experience greater path loss than lower-frequency LTE bands. For many years, the standard solution for this coverage gap in large venues was the Active Distributed Antenna System (DAS). DAS setups depend on a central signal source that distributes signals through a complex network of fiber and coaxial cables. Although effective, DAS systems are costly and slow to deploy, typically reserved for the most prominent "Tier 1" venues [2].

B. The Rise of the "Middle Enterprise" Gap

A significant market failure has emerged in the "middle enterprise" sector, which includes commercial real estate, hotels, hospitals, and industrial facilities spanning from 100,000 to 500,000 square feet. These venues require reliable cellular connectivity but often lack the capital needed for traditional DAS deployment. Market analysis indicates that the neutral-host market opportunity will expand considerably, driven by enterprises adopting shared infrastructure models to reduce costs and cut carbon emissions [3]. Consequently, these enterprises are increasingly relying on Wi-Fi for data, creating a critical gap for voice services and essential, low-latency applications that Wi-Fi cannot consistently support.

C. The Neutral Host and Private Network Convergence

The Neutral Host Network (NHN) model has emerged as a key solution to this economic deadlock. By definition, a Neutral Host is a third-party wireless infrastructure that enables multiple MNOs to serve their subscribers using a single, shared Radio Access Network (RAN) [4]. This model is gaining traction because of its mutually beneficial relationship with Private Wireless Networks (PWN).

The modern business requires a "Hybrid" network that supports:

1. **Public Access:** Seamless voice and data services for employees and visitors using SIM cards from national carriers.
2. **Private Access:** A secure, locally managed network slice for Operational Technology (OT), such as Autonomous Mobile Robots (AMRs) and IoT sensors.

This paper argues that the Neutral Host model is the key driver for Private 5G adoption by addressing the ROI challenge. By spreading the infrastructure costs across both public carrier offload and private enterprise use, NHNs make the business case for private cellular services feasible for the mass market.

II. ARCHITECTURAL FRAMEWORK OF NEUTRAL HOST NETWORKS

The effectiveness of a Neutral Host deployment depends on the specific architecture used for resource sharing. 3GPP standards outline a range of sharing methods, from passive site sharing to active core network integration.

A. Distributed Antenna Systems (DAS) vs. Small Cell Architectures

To understand the innovation of modern NHNs, you need to compare them with legacy DAS.

- **Legacy DAS:** Traditionally, DAS serves as an analog RF distribution method. It needs a dedicated base station for each participating carrier at the head-end, which uses a large amount of power and space [5].
- **Small Cell NHN:** Modern NHNs use small cells, which are compact, low-power wireless access points that connect via standard Ethernet (LAN) cables. In a Neutral Host setup, these small cells are "multi-tenant" capable, broadcasting the PLMN IDs of multiple operators simultaneously [4].

B. Multi-Operator Radio Access Network (MORAN)

The MORAN architecture represents a "Shared RAN, Dedicated Spectrum" model.

- **Mechanism:** In MORAN, the radio hardware is shared, but each MNO uses its own licensed frequency spectrum. The shared radio head must be capable of transmitting on multiple disparate frequency bands simultaneously [6].
- **Implications:** This enables MNOs to fully control their capacity planning and interference management. It is often the preferred choice for MNOs cautious about sharing spectrum resources.

C. Multi-Operator Core Network (MOCN)

MOCN is the most transformative architecture for expanding Private 5G, particularly in shared-spectrum environments like CBRS.

- **Mechanism:** MOCN enables "Shared RAN, Shared Spectrum." Multiple MNOs share the same radio hardware and the same frequency carrier [6]. The RAN broadcasts the PLMN IDs of all participating networks, directing signaling to the correct MNO's core network based on the SIM card's identity [7].
- **Strategic Advantage:** This architecture enables an enterprise to deploy a single layer of radios, such as in the CBRS 3.5 GHz band, and serve users on AT&T, Verizon, and T-Mobile networks

simultaneously. It provides the highest spectral efficiency and the lowest hardware costs.

D. Gateway Core Network (GWCN)

GWCN extends sharing further into the network, including Core Network elements like the Mobility Management Entity (MME).

- **Mechanism:** The shared RAN connects to a common MME, which then links to the individual operators' HSS and P-GWs [7].
- **Adoption Status:** Although GWCN is theoretically more efficient, its practical adoption remains limited because MNOs prefer to keep their core control plane functions separate for security and reliability.

Table 1: Comparison of Network Sharing Architectures [7] [8]

Feature	MORAN (Multi-Operator RAN)	MOCN (Multi-Operator Core Network)	GWCN (Gateway Core Network)
Shared Elements	Antennas, Base Station Hardware, Site	Antennas, Base Station, Spectrum	Antennas, Base Station, Spectrum, Core (MME/AMF)
Spectrum Usage	Dedicated (Per Operator)	Shared (Pooled)	Shared (Pooled)
Spectral Efficiency	Low (Fragmented)	High	High
Operator Control	High	Medium	Low
Primary Use Case	Legacy DAS, Macro Tower Sharing	CBRS Neutral Host, Private 5G	Niche / Rural Coverage
Cost Savings	Moderate	High	Very High
Security Perception	Trusted by MNOs	Generally Accepted	Resistance from MNOs

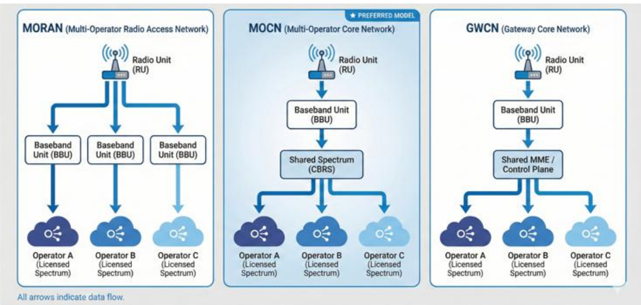

Figure 1: Comparing MORAN vs MOCN vs GWCN Architectures

III. SPECTRUM DYNAMICS AND STANDARDIZATION

The viability of the MOCN Neutral Host model depends heavily on the availability of spectrum that can be shared or accessed by non-MNO entities.

A. The CBRS Revolution (Band 48)

In the United States, the Citizens Broadband Radio Service (CBRS) has been a key regulatory innovation. The FCC opened 150 MHz of spectrum in the 3.55-3.70 GHz band for shared commercial use [9].

- **Democratization:** Before CBRS, only MNOs with licensed spectrum could legally run a cellular network. CBRS enables enterprises to set up their own LTE/5G networks [10].
- **Neutral Host Enablement:** This "neutral" spectrum is an ideal medium for MOCN. A third-party provider sets up the infrastructure on CBRS spectrum, and MNOs roam onto it [10].

B. 3GPP Release 16 and 17: Non-Public Networks

The 3rd Generation Partnership Project (3GPP) has formalized support for private networks (Non-Public Networks or NPNs) [11].

- **Release 16** introduced SNPN (Stand-alone Non-Public Network) and PNI-NPN (Public Network Integrated NPN) [11].
- **Release 17** enhanced support for neutral hosts by allowing a User Equipment (UE) to access an SNPN using credentials from a different entity (Credentials Holder), further separating subscription ownership from network infrastructure ownership [11].

IV. TECHNO-ECONOMIC ANALYSIS

The main driver for moving from DAS to Neutral Host MOCN is cost efficiency. This section combines TCO data to measure the benefits.

A. CAPEX and OPEX Reductions

CBRS-based Neutral Host networks using MOCN small cells have been shown to reduce Capital Expenditures (CAPEX) by 50-70% compared to traditional DAS [10].

Key Cost Drivers:

1. **Hardware Consolidation:** In MOCN, adding a carrier is a software configuration change in the core gateway that requires no new site visits or hardware.
2. **Energy Efficiency:** Active DAS head-ends require substantial cooling and power. Small cells are highly energy-efficient. Case studies show that Distributed Radio Systems can reduce energy consumption by up to 70% compared to active DAS, which directly lowers Operating Expenses (OPEX) [12].

B. TCO Modeling Parameters

Mathematical models for 5G Non-Public Network architectures identify "Cost Saving Strategies" and "Deployment Type" as key parameters. A study by Frank et al. derives the CAPEX function as:

$$CAPEX = Cost_{Eq} + Cost_{Infra} + Cost_{Insta} + Cost_{License}$$

Where $Cost_{Eq}$ (Equipment) and $Cost_{Insta}$ (Installation) are dramatically lower in NHN deployments due to the use of off-the-shelf enterprise switching gear and the elimination of proprietary RF plumbing [13].

C. Performance Comparison: Wi-Fi 6 vs. Private 5G

While Wi-Fi 6 is often seen as an affordable alternative, it doesn't meet the Service Level Agreements (SLAs) needed for industrial automation.

Table 2: Performance Comparison - Private 5G vs. Wi-Fi 6 [14]

Metric	Private 5G (Neutral Host)	Wi-Fi 6 (802.11ax)	Implication
Latency	< 10 ms (Deterministic)	10 - 30 ms (Best Effort)	5G required for real-time robotics control [15].
Reliability	99.999% (5 Nines)	Variable / Best Effort	5G technology achieved 75% higher reliability in industrial settings [16].
Mobility	Seamless Handover (>50 km/h)	Limited (Sticky Clients)	5G essential for AGVs moving across large warehouses [17].
Device Density	~1 million / sq. km	Limited per AP	5G supports massive IoT sensor deployments [18].
Security	SIM-based (Military Grade)	WPA3 (Password based)	5G offers superior protection against rogue access points [19].

V. CASE STUDIES AND EMPIRICAL VALIDATION

Real-world deployments provide the most substantial evidence of the effectiveness of Neutral Host models across different environments.

A. Meta (Facebook): Corporate Office Coverage

Challenge: Meta faced the dual challenge of limited cellular coverage in its energy-efficient office buildings and the high cost of deploying DAS [20].
Solution: Meta partnered with a Neutral Host provider to deploy a CBRS-based MOCN network. This system used small cells to broadcast signals for AT&T, Verizon, and T-Mobile [20].
Results: The project showed a 75% reduction in deployment time compared to traditional DAS. By utilizing shared spectrum, Meta achieved widespread indoor coverage at a fraction of the cost [20].

B. Cummins Jamestown Engine Plant: Industrial Hybrid

Challenge: The 2-million-square-foot Cummins plant in New York needed to support 1,500 employees (public use) and a fleet of Autonomous Mobile Robots (private use) [21].
Solution: Cummins deployed a hybrid network with Verizon serving as the anchor tenant. The network uses Verizon's licensed C-band spectrum for private industrial slices and functions as a neutral host for employee connectivity [21].
Results: The private 5G slice enabled machine vision for defect detection and AMRs for material transport, increasing productivity. The neutral host component ensured staff had reliable voice and data service [21].

C. University of Virginia (UVA): Campus Safety

Challenge: Legacy buildings and underground areas on the UVA campus were cellular dead zones, creating safety hazards [22] [23].
Solution: A CBRS Neutral Host network was deployed, enabling AT&T and T-Mobile to roam onto the university-owned infrastructure [22] [23].
Results: This effectively expanded public carrier coverage into "hard-to-reach" areas without requiring carriers to build new towers or install proprietary DAS, significantly improving the safety net for students and faculty [22] [23].

VI. CHALLENGES AND REGULATORY LANDSCAPE

Despite the technical and economic advantages, several obstacles hinder widespread adoption.

A. Security and Core Network Integration

MNOs have traditionally protected their core networks. Connecting a third-party Neutral Host RAN to an MNO Core creates potential security vulnerabilities.

Challenge: Ensuring that a compromised small cell in an enterprise cannot initiate a signaling storm or a Denial of Service (DoS) attack against the national carrier network [24].

Mitigation: 3GPP standards mandate strict security gateways (SeGW) and mutual authentication. Additionally, network slicing is used to decouple functions and improve security [24].

B. Roaming Friction and Control

Challenge: While technology enables roaming, commercial agreements act as the bottleneck. MNOs are often hesitant to give up control over the quality of service (QoS) to a third-party infrastructure owner [25].

Solution: The market has adopted the "Aggregator" model. However, MNOs still express concern that neutral hosts reduce their control over service standards [25].

VII. FUTURE OUTLOOK

The trajectory of Neutral Host Networks is moving toward more disaggregated and intelligent architectures, driven by the rise of 6G and Open RAN.

A. Open RAN and Virtualization

The future of Neutral Hosting aligns with network disaggregation. Open RAN (O-RAN) enables virtualization of the Baseband Unit (BBU), allowing the "Host" function to run as software on standard servers. Recent research into "NeutRAN" architectures shows how O-RAN based neutral hosts can support zero-touch RAN and spectrum sharing, lowering barriers for third-party operators [26]. This virtualization facilitates more dynamic resource sharing, as industry bodies predict [27].

B. 6G and AI-Native Networks

Looking further ahead, 6G will likely introduce "Integrated Sensing and Communication" (ISAC) and AI-native air interfaces. In these next-generation networks, neutral hosts will play a critical role in managing the extreme densification required for higher frequency bands. Recent surveys on 6G indicate that AI will be central to optimizing resource allocation in these complex, multi-tenant environments, enabling neutral hosts to dynamically balance load across public and private slices in real time [28] [29]. Furthermore, new business models, such as the "Micro-Operator," are emerging to efficiently manage these citywide neutral-host deployments [30].

VIII. CONCLUSION

The Neutral Host model has evolved from a niche solution for rural coverage to a key part of the Private 5G ecosystem. By addressing the connectivity gap for mid-sized enterprises through the cost-effective MOCN architecture and CBRS spectrum, NHNs unlock Industry 4.0's potential. The ability to layer private, deterministic OT networks on the same infrastructure used for public employee connectivity offers a strong ROI that neither legacy DAS nor Wi-Fi can provide. As regulatory frameworks become more standardized and MNOs grow more comfortable with shared infrastructure, Neutral Host networks will likely become the default choice for enterprise wireless connectivity.

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