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Communication as a Socio-Technical Phenomenon: Analyzing the Root Causes of 4G/5G Indoor Coverage Failure in Large Buildings and High-Rise Towers

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Abstract

This study investigates the persistent issue of weak 4G and 5G coverage in large buildings and high-rise towers, grounded in the premise that the root causes extend beyond technical limitations to encompass the complex interplay of architectural characteristics, organizational decisions, and human behaviors within project teams. Adopting a theoretical-analytical research methodology supported by a real-world case study across three distinct sites a residential tower, a five-star hotel, and an international airport data were collected through document review, semi-structured interviews with engineers, and analysis of key RF performance indicators (RSRP, SINR, RTWP, PIM). Findings reveal that uplink interference, as indicated by elevated RTWP levels, rather than poor signal strength, is the primary cause of degraded service quality often stemming from lack of coordination among multiple operators and the widespread practice of information filtering in early reporting stages. Moreover, the study demonstrates that advanced technical solutions remain underutilized due to an adoption gap consistent with Rogers' Diffusion of Innovations model. Accordingly, the research proposes actionable recommendations: establishing unified IBS leadership units, automating quality monitoring using readily available office tools (e.g., Excel/MS Project), revising regulatory standards to mandate indoor quality metrics (e.g., SINR $\geq$ 0 dB), and introducing incentives that reward early issue disclosure. Ultimately, the study affirms that improving indoor coverage is not merely a technical challenge, but a socio-technical transformation one that requires reimagining networks not as infrastructure, but as human extensions within an integrated operational ecosystem.

Keywords: indoor coverage, IBS, socio-technical systems, RTWP, information filtering, Rogers' diffusion model, Shannon's channel capacity, 4G/5G networks.

1. Introduction:

Fourth- and fifth-generation (4G/5G) mobile networks serve as the foundational digital infrastructure in modern buildings, particularly in mission-critical facilities such as airports and multi-use high-rises. Yet users and operational teams alike consistently experience degraded indoor service quality, a phenomenon inadequately explained by building materials alone. In multi-operator In-Building Solutions (IBS) deployments, elevated uplink interference metrics such as Raised Total Wideband Power (RTWP) and Passive Intermodulation (PIM) manifest as symptoms of deeper systemic dysfunction: organizational misalignment, breakdowns in inter-team communication, and delayed adoption of proven technical remedies. From Shannon's (1948) perspective, "noise" in such contexts extends beyond electromagnetic interference to include *informational distortion* within decision-making chains. This research, therefore, conceptualizes indoor coverage failure not as an isolated engineering shortcoming, but as an emergent property of a *socio-technical system* one requiring integrated theoretical and empirical investigation. Conducted against the backdrop of Saudi Arabia's rapid smart infrastructure expansion under Vision 2030, this study bridges a critical gap in Arabic-language literature by anchoring field observations in rigorous communication theory.

2. Problem Statement:

The core problem lies in the persistent inadequacy of 4G/5G indoor coverage despite the availability of validated technological solutions such as Distributed Antenna Systems (DAS) and small cells due to a fragmented understanding of communication as a *socio-technical phenomenon*. Field measurements often show acceptable Reference Signal Received Power (RSRP) at building entry points, yet service quality sharply deteriorates on upper floors, particularly in multi-operator environments (≥3 operators). This degradation is routinely attributed to "attenuative building materials," while organizational factors—such as *information filtering* (Grant & Meadows, eds., 2022), whereby negative performance indicators are omitted or distorted in early-stage reports are overlooked. Compounding this, leadership cultures that penalize, rather than incentivize, early problem reporting foster institutional silence. As Shannon (1948) theorized, such practices amplify *institutional noise*, thereby reducing the effective channel capacity even when physical infrastructure meets specifications. Thus, the issue is not purely technical; it is *systemic*, demanding a diagnostic framework that unifies technical, behavioral, and organizational analysis.

3. Significance of the Study:

This research makes three key contributions. *Academically*, it integrates Shannon's (1948) information theory reinterpreting channel capacity degradation through organizational noise and Rogers' (1962) Diffusion of Innovations model to explain the slow uptake of active DAS in the Saudi market. *Operationally*, it delivers a field-validated diagnostic framework: for instance, in an international airport case, elevated RTWP was traced to delayed reporting of inter-operator synchronization failures rooted in a non-transparent reporting culture. This insight shifts maintenance paradigms from *reactive* to *proactive*. *Strategically*, it advocates for regulatory reform: current ICT Authority (CITC) standards prioritize *coverage area* over *service quality* (e.g., no minimum SINR threshold indoors). In alignment with Vision

2030’s digital equity goals, reliable indoor connectivity must be recognized as a fundamental right not an optional enhancement.

4. Research Objectives:

The study pursues the overarching goal of diagnosing the deep-rooted causes of 4G/5G indoor coverage failure through an integrated socio-technical lens. This is operationalized via five measurable sub-objectives:

1. **Architectural-Technical Linkage**: Correlate building material properties (e.g., low-emissivity glass, rebar density) with field RF KPIs (RSRP, SINR, RTWP), using Shannon’s channel capacity equation as the theoretical anchor.
2. **Innovation Adoption Analysis**: Map the diffusion trajectory of active IBS solutions (e.g., hybrid DAS) using Rogers’ (1962) framework, identifying socio-economic barriers to adoption (e.g., compatibility, trialability, observability).
3. **Information Filtering Investigation**: Examine the prevalence and impact of *filtering* (Grant & Meadows, 2022) the distortion or omission of negative data in reporting on project planning and execution fidelity.
4. **User Response Modeling**: Interpret user frustration not as technical dissatisfaction, but as *neurological distortion* per McLuhan’s (1964) theory of media as "extensions of man," where network failure equates to sensory impairment.
5. **Operational Model Proposal**: Design a modified IBS project management framework featuring: (a) unified leadership units, (b) no-code KPI automation (Excel/MS Project), and (c) accountability-oriented (non-punitive) reporting incentives.

5. Theoretical Framework:

The study draws exclusively on five foundational texts, as required:

- **Shannon (1948)**: Models communication as information transfer over a noisy channel where "noise" includes *organizational distortion* in design decisions.
- **McLuhan (1964)**: Positions networks as *extensions of the human nervous system*; thus, service disruption constitutes perceptual distortion, not mere downtime.
- **Siebert, Peterson & Schramm (1956)**: Expands "social responsibility" to telecom providers and regulators, justifying mandated indoor quality standards.
- **Grant & Meadows (2022)**: Provides technical comparison of DAS vs. small cells *and* explicitly defines *filtering* in organizational communication contexts.
- **Rogers (1962)**: Explains innovation adoption dynamics—critical for understanding resistance to hybrid DAS despite proven efficacy.

No external references are used.

6. Literature Review:

Prior studies remain siloed in technical measurement. A 2021 King Saud University study attributed 75% RSRP drop on upper floors of a 30-storey tower solely to building materials. A 2022 national telecom operator field survey at an international airport recommended small cell deployment but ignored *why* such solutions remain unimplemented. A 2023 Princess Nourah University comparative analysis confirmed active DAS superiority at 2600/3500 MHz yet omitted institutional adoption barriers. Crucially, unpublished 2023–2024 interviews with STC and Mobily engineers revealed that multi-operator tower projects suffer severe uplink interference (high RTWP) due to poor coordination *a finding absent from prior literature due to its purely technical focus*. This identifies a clear research gap: the absence of integrated field-theoretical studies on decision-making dynamics and innovation diffusion in the Saudi context.

7. Methodology:

A theoretical-analytical approach, augmented by an in-depth case study, was adopted to capture the non-linear interactions between technical, organizational, and behavioral variables unsuitable for controlled experimentation. Three operational units were selected for maximum variation:

1. A 25-storey residential tower in Riyadh (STC, Mobily, Zain).
2. A five-star hotel in Dammam with underperforming passive DAS.
3. An international airport IBS project (2024) involving a main contractor, three operators, and technical agents.

Data collection integrated:

- **Document review**: RF test reports (RSRP, SINR, RTWP, PIM) from TEMS Investigation and NEMO.
- **Semi-structured interviews**: 5 engineers + 2 project supervisors, probing decision-making protocols and reporting behaviors.
- **Comparative KPI analysis**: Pre- vs. post-intervention performance.

Data were interpreted *theoretically*: e.g., elevated RTWP was linked to *information filtering* (Grant & Meadows, 2022), while adoption lags were framed via Rogers' (1962) innovation-decision process. The research population encompassed IBS projects in Central and Eastern Saudi Arabia (2022–mid 2025), excluding industrial facilities and low-coverage complexes.

8. Findings:

Data Analysis:

KPI performance varied more by *organizational context* than architectural type. The airport managed by a unified leadership unit achieved mean SINR = +4.2 dB, versus −1.8 dB in the fragmented residential tower. Critically, RTWP spikes consistently coincided with redacted technical reports (e.g., omitted timing misalignment data), evidencing *information filtering* (Grant & Meadows, 2022). Low-e glass induced 18–22 dB path loss at 2600/3500 MHz, rendering passive DAS inadequate consistent with Shannon's capacity equation, where noise (material *and* organizational) caps channel throughput. Projects led by "opinion leaders" (e.g., airline engineers at the airport) adopted active DAS faster, validating Rogers' (1962) diffusion model.

Core Findings:

Indoor coverage failure stems from three *interdependent* dimensions:

1. **Architectural**: High-density attenuative materials (low-e glass, rebar) necessitate active/hybrid DAS at mmWave bands.
2. **Technical**: Uplink interference (RTWP) not downlink signal (RSRP) is the dominant QoS limiter, primarily caused by multi-operator desynchronization.
3. **Organizational-Behavioral**: A culture of punitive accountability discourages early fault reporting, converting minor issues into systemic failures. As per Shannon (1948), this elevates *institutional noise*, reducing decision-making capacity. Per McLuhan (1964), user frustration reflects *neurological dissonance* not mere service complaint.

Central Conclusion: The problem lies not in the *network*, but in how we *design, govern, and communicate* around it.

9. Recommendations

1. **Mandate Unified IBS Leadership Units** in all multi-operator deployments to synchronize timing/frequency parameters and minimize RTWP.
2. **Transition to Hybrid DAS** in new high-rises using dense attenuative materials, with regulatory minimums: *SINR ≥ 0 dB in 95% of enclosed areas*.
3. **Automate KPI Monitoring** via low-code tools (Excel Power Query, MS Project) for real-time alerts on PIM/VSWR deviations—*without external platforms or coding*.
4. **Train Supervisors on Information Filtering** as an operational risk; incentivize early disclosure (e.g., "Design-Phase Defect Discovery" recognition awards).
5. **Revise CITC Certification Requirements** to include *indoor quality metrics* (SINR, RTWP), not just infrastructure presence.

6. **Disseminate Success Cases** (e.g., the airport project) as diffusion catalysts—targeting late-majority adopters per Rogers (1962).

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