Private 5G NR Networks: Analytical Framework for Radio Interface Delays in Industrial Deployments

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Abstract:

Private 5G networks, also referred to as Captive Non-Public Networks (CNPNs), are increasingly deployed to support latency-critical and heterogeneous services in industrial and campus environments. Maintaining a wireless network in scenarios of refineries, open and underground mines and ports is one of the major challenges that system integrators and network engineers face. Equipment is large, on the move and never in line of sight to other network devices.

Mining operations are dusty, loud and in challenging environments that take a toll on wireless equipment. After a significant investment in a wireless network, many face frustration with deficiencies in network uptime and durability. Accurate evaluation of processing latency in such networks requires transparent and traceable modeling of individual latency components across protocol layers. This paper presents a component-based latency analysis framework for 5G New Radio (NR) downlink transmissions, specifically tailored to CNPN scenarios.

The proposed methodology decomposes latency into traffic generation, MAC layer queueing and scheduling, physical layer processing and transmission components. Traffic arrivals are modeled using periodic, aperiodic and mixed generation processes to reflect realistic private network workloads. Downlink scheduling is performed using deterministic, rule-based policies to ensure reproducibility and analytical clarity. Physical layer latency is evaluated based on NR numerology, bandwidth, modulation and coding schemes and retransmission behavior. The component-wise decomposition enables clear identification of latency bottlenecks and provides valuable insights for the design and dimensioning of latency-sensitive CNPN deployments.

Keywords:

5G NR, CNPN, URLLC, Scheduling, Radio resource blocks, Latency.