Inter-Network Interference in Private 5G: An Empirical Study in Urban Environments

Hyeyeon Kwon
Radio Research Division
Electronics and Telecommunications Research Institute
Daejeon, Korea
hykwon@etri.re.kr

Kyungyul Cheon
Radio Research Division
Electronics and Telecommunications Research Institute
Daejeon, Korea
kycheon@etri.re.kr

Kyungwon Kim
Radio Research Division
Electronics and Telecommunications Research Institute
Daejeon, Korea
kimkw@etri.re.kr

Hyeonsik Yoon
Radio Research Division
Electronics and Telecommunications Research Institute
Daejeon, Korea
x7hyhs@etri.re.kr

Seungkeun Park
Radio Research Division
Electronics and Telecommunications Research Institute
Daejeon, Korea
seungkp@etri.re.kr

***Abstract*—Private 5G (P5G) networks, also known as 'e-um 5G' in South Korea, have garnered significant interest for their ability to provide localized and dedicated wireless communication. However, the absence of unique Public Land Mobile Network Identifications (PLMN IDs) in the current e-um 5G deployments makes it challenging to distinguish base stations by network identity, potentially leading to signal interference issues such as Physical Cell ID (PCI) conflicts and coverage overlaps. In this study, we conduct a measurement-based analysis of private 5G coverage and interference in an urban environment with multiple deployed private networks. A drive test was performed around three buildings with separate private networks, and key signal parameters, including Reference Signal Received Power (RSRP), Signal to Interference Noise Ratio (SINR), PCI, and Beam Index (BI), were collected. The Service Coverage Map was generated to visualize signal coverage and interference coordination area. The analysis revealed that the same PCI 201 was strongly observed around both Building 1 and Building 2, suggesting that one or both of the buildings are operating base stations using the same PCI. Additionally, signal strength measurements reveal excessively high transmission power from Building 2, leading to a concentrated high-signal region. These findings highlight the potential risk of PCI confusion and interference, which could degrade network performance. To mitigate such interference, further optimization of base station deployment, transmission power control, and PCI planning are required. This study provides insights into interference management for private 5G networks and proposes key directions for optimizing private 5G deployment strategies.**

Keywords—Private 5G, e-um 5G, PCI interference, Coverage Analysis, Service Coverage Map

I. Introduction

With the acceleration of digital transformation, mobile communication technology is expanding across industries, creating new opportunities in B2B sectors like Industry 4.0. As 5G convergence services extend into various vertical domains, a new type of network has emerged: The P5G Network, classified as a Non-Public Network (NPN), which differs from traditional nationwide Public Networks (PN).

The NPNs operate independently from PNs, which are managed by mobile network operators (MNOs). Unlike public networks, NPNs are designed to provide customized mobile communication services within limited geographic area (enterprise sites, factories, or campuses) while utilizing the same frequency bands as PNs. As a result, there is a high potential for interference between adjacent NPN base stations that share the same frequency spectrum[1]

A P5G is a dedicated enterprise network that extends the capabilities of public 5G networks, such as ultra-high speed, ultra-low latency, and massive connectivity, while utilizing a separate frequency band. This allows P5G networks to offer enhanced security, independence, and flexibility, making them ideal for enterprise applications requiring specialized network environments.

In South Korea, the P5G service was first introduced in 2021 under the name 'e-um5G'. It utilizes IMT technology standards (IMT-2020 and its evolutionary technologies) adopted by the ITU to establish and operate wireless networks within designated areas such as buildings. The e-um 5G embodies the three core features of 5G: enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (uRLLC), and massive Machine Type Communications (mMTC), emphasizing its role in connecting devices and society[2].

The e-um 5G refers to a customized network that operates on dedicated spectrum (4.72 GHz, 28 GHz), separate from commercial mobile networks, and is designed for use within specific spaces such as buildings or land[2]. It can be deployed within the same frequency band to support specific services for individual business sites. The area where such a private network is established is defined as the Private Network Usage Area (PNUA). The PNUA is limited to buildings or land owned by the entity applying for the private network, or areas where permission (or consent) has been obtained from third parties.

To ensure seamless service provision, the coverage range and radio propagation range are regulated under South Korea's P5G policy to facilitate the operation of private networks while minimizing interference with existing networks.

The Service Coverage Area (SCA) defines the radio propagation range where optimal network performance is guaranteed. From the user's perspective, the SCA represents the expected signal reach that ensures maximum throughput, typically defined as the area where the signal strength reaches -105 dBm (SS-RSRP ≥ -105dBm).

Meanwhile, the Interference Coordination Area (ICA) is defined as the radio propagation range used to assess potential interference with existing radio stations. The ICA is determined by the expected distance where the received signal power reaches -115 dBm (SS-RSRP ≥ -115 dBm).

Fig. 1 illustrates the South Korea's P5G coverage guidelines for the usage area and radio propagation regions[2][3].

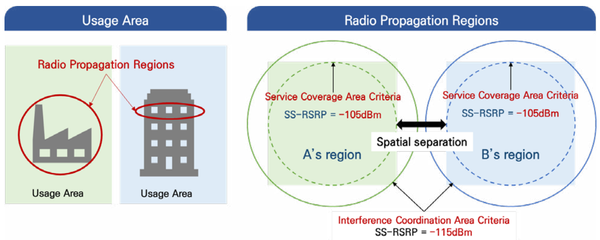

Fig. 1. e-um5G Usage Area and Radio Propagation Regions

The SCA and ICA are defined as regions that ensure maximum throughput from the user's perspective. However, as demand increases and multiple business sites emerge in adjacent areas, interpreting the SS-RSRP used to define the SCA and ICA becomes challenging. This issue arises because different network providers may implement distinct SSB (Synchronization Signal Block) patterns, such as Fixed Beam or Multibeam with Beam Sweeping, leading to variations in SS-RSRP interpretation.

Additionally, the SS-RSRP value of interference signals represents only an instantaneous indicator of signal strength at a specific point in time. The actual signal quality of the service beam can only be measured in the dedicated mode of authorized user devices. Therefore, relying solely on simple channel scanning devices is insufficient for accurately evaluating the true signal quality of the service beam.

Meanwhile, the PCI, which is a unique identifier for identifying a wireless cell, is arbitrarily assigned by either the network operator responsible for deploying and managing the network at a specific site or the user who configures a private network independently[4].

PCI is closely related to the Synchronization Signal (SS), which enables a device to detect the presence of the wireless network (cell search) and obtain frame timing. Therefore, when two or more cells share the same PCI, a PCI collision occurs, leading to synchronization delays during cell search and making cell selection and channel estimation more difficult. For this reason, physical separation between cells using the same PCI is crucial, and proper PCI planning is required when designing a wireless network.

However, unlike commercial networks where a single mobile network operator exclusively manages a dedicated frequency band, e-um 5G networks are independently deployed by multiple business entities operating private networks. As a result, PCI collisions between adjacent business sites are more likely to occur, necessitating a different approach to PCI allocation and interference management compared to conventional mobile networks.

Although e-um 5G in South Korea have rapidly advanced, prior studies primarily focus on theoretical spectrum allocation and lack comprehensive real-world analyses of interference in urban P5G environments. Moreover, the impact of overlapping PCI allocations on network performance remains insufficiently explored.

This study aims to clearly address the identified gaps by empirically analyzing P5G coverage and interference using real-world measurements in a multi-building e-um 5G deployment. By evaluating key signal parameters (RSRP, SINR, PCI, and BI) and visualizing the Service Coverage Map (SCMap), we provide a detailed assessment of network performance and interference risks. This thereby contributes guidance for optimized PCI planning, transmission power control, and base station deployment strategies to enhance P5G stability and inform future e-um 5G rollouts.

II. Methodology

A. *Measurement System/Setup*

In this study, we utilized a custom-developed 5G scanner and monitoring system. The 5G scanner is a hardware device designed to measure PCI, signal power, and inter-cell interference in cell boundary areas, capable of detecting very low signal levels (-115 dBm to -130 dBm). Measurements were conducted under relatively stable environmental conditions (clear sky, low pedestrian traffic) to minimize external interference and ensure consistency in data collection.

Additionally, the scanner is equipped with Polar decoding and LDPC decoding capabilities, allowing it to decode the Physical Broadcast Channel (PBCH) to extract the Master Information Block (MIB) message. Based on this information, it further decodes System Information Block 1 (SIB1) to obtain system details, including the PLMN ID, which identifies the mobile network operator. This enables the identification of potential interference sources.

Fig. 2 shows the real-world measurement setup. The left side of the figure depicts the field measurement in progress inside a vehicle, while the right side displays the self-developed 5G scanner and its control device used for data collection. The measurements include key parameters such as RSRP, SINR, PCI, and BI, aiding in the analysis of network coverage and signal characteristics. The data collected by the 5G scanner is transmitted in real-time to the monitoring system, allowing for real-time network analysis and interference detection. The real-time monitoring system enables the analysis of 5G signal coverage, interference areas, and key network parameters and displays the base station locations provided by the P5G network operator, along with their SCA and ICA on the map.

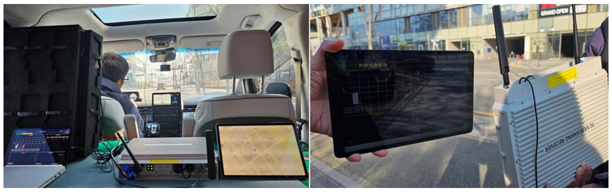

Fig. 2. On-Site Measurement and Custom-Developed 5G Scanner

B. Test Environment and Data Collecion

Fig. 3 illustrates the field test environment in an urban area of Sejong, South Korea. The test site includes multiple buildings (Building 1 and Building 2), a shopping mall (Mall), and a two-lane road, with arrows indicating measurement perspectives. Building 1 and Building 2, operated by the same private network provider, are located approximately 135 m apart across a two-lane bidirectional road, while Building 1 and the Mall, served by a different provider, are about 200 m apart. The map highlights measurement locations and corresponding signal reception views, aiding in the analysis of network coverage and signal strength variations.

Fig. 3. Visualization of the Field Test Environment

Fig. 4 shows the drive test route and signal measurements for e-um 5G in an urban environment. The left side of the figure shows the test route around Building 1, Building 2, and Mall, marked with different courses (walking and driving). The right side of the figure displays recorded signal parameters, such as RSRP, SINR, and PCI, at various measurement points.

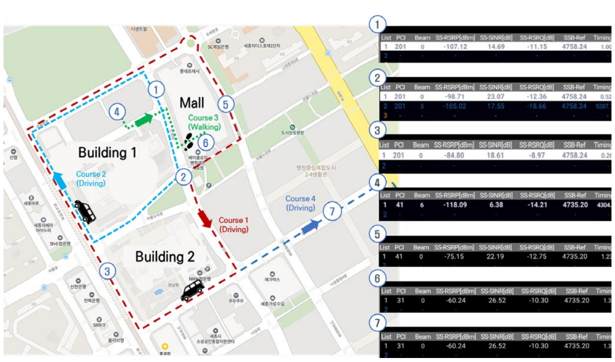

Fig. 4. Drive Test Route and Signal Measurement for e-um 5G

This test setup helps analyze signal coverage, interference, and network performance across different locations. Numbered circles (①, ②, ③, ④, ⑤, ⑥, ⑦) are marked on the map pointing to specific locations where signal characteristics are highlighted for detailed analysis.

C. Coverage and Interference Analysis Model

A SCMap depicting both the SCA and the ICA can be created using information from the base stations installed in each building.

Each base station's coverage is estimated using factors such as bandwidth, transmission power, antenna gain and path loss calculated based on ITU-R P.1411-1 or 3GPP TR 38.901 recommendations. The propagation environment is classified as either Line-of-Sight (LOS) or Non-Line-of-Sight (NLOS). The LOS environment refers to cases where the transmitted signal is not obstructed by obstacles, whereas the NLOS environment accounts for signal obstructions caused by surrounding objects. Additionally, the Building Entry Loss (BEL) model follows ITU-R P.2109, reflecting modern building characteristics. BEL represents the total signal loss occurring as the radio wave penetrates the building structure and experiences additional attenuation indoors. BEL varies depending on the building type (older vs. modern buildings), with modern buildings exhibiting higher power loss due to the use of thermal insulation materials. Since both path loss and BEL are based on statistical models, coverage radius calculations are determined using their median values.

The area surrounding the private network-installed buildings consists mainly of open spaces and roads, with most buildings constructed within the last decade. Therefore, BEL is modeled based on modern buildings, and since the exact locations of base stations are not precisely known, the worst-case scenario was considered by applying NLOS conditions, which accounts for potential obstructions affecting signal propagation.

III. Results

A. Signal Measurement Results

Fig 5. illustrates the spatial distribution of signal measurements and the estimated coverage areas of P5G networks in an urban environment. Numerous small colored dots are scattered across the map, representing the individual measurement points where signal data was collected during the drive test. The color of each dot indicates the dominant PCI detected at that specific location:

- Purple dots(201): Indicate locations where PCI 201 was the strongest detected signal.
- Red dots(41): Indicate locations where PCI 41 was the strongest detected signal.
- Blue dots(31): Indicate locations where PCI 31 was the strongest detected signal.

PCI 201 is predominantly observed around Building 1 and Building 2, suggesting that a base station in one or both of these buildings is using PCI 201. PCI 41 and PCI 31 are dominant near the Mall, indicating that the base station installed in the Mall is operated on these PCIs.

The following table summarizes the key performance indicators for each private network, with a focus on the highest signal measurements and the observed instances of PCI confusion and coverage overlap.

TABLE I. TABLE TYPE STYLES

PCI	Peak RSRP (dBm)	Measurement Location	SINR at Peak RSRP (dB)	PCI Confusion	Coverage Overlap
201	-70.32	Between Building 1 & 2	27.17	0	0
31	-61.93	Inside the Mall	26.24	x	x
41	-58.46	Behind the Mall	29.91	x	x

The visualization provides a clear understanding of the signal distribution, which aids in analyzing network coverage, identifying potential interference zones, and evaluating base station deployments in the area.

B. Service Coverage Map Analysis

Fig 5. also shows the SCMap with red circle and yellow circle. The large red circles on the map represent the SCA for specific base stations. The SCA is defined as the radio propagation range where optimal network performance is guaranteed, typically where the SS-RSRP is greater than or equal to -105 dBm. There is a red circle around Building 2, and another one around the Mall, indicating the estimated optimal service regions for base stations in those vicinities.

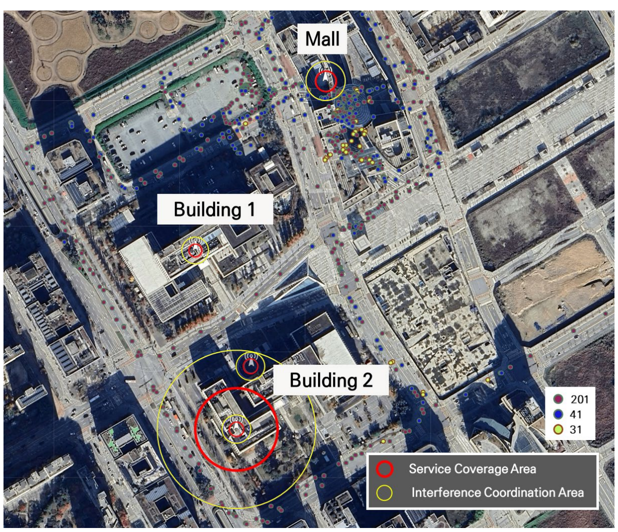

Fig. 5. Service Coverage Map

The larger yellow circles on the map represent the ICA. The ICA is defined as the radio propagation range used to assess potential interference with existing radio stations, where the SS-RSRP is greater than or equal to -115 dBm. Yellow circles are visible around Building 2 and the Mall, encompassing broader areas where interference assessment is relevant.

The red and yellow circles (SCA and ICA) visually represent the estimated coverage characteristics, indicating where signals are strong enough for optimal service and where potential interference could occur. The overlap of these areas, especially where different PCIs are observed, points to potential challenges in interference management.

Fig. 6 illustrates the signal strength distribution of PCI 201 using color-coded markers based on location. The red and orange markers, representing strong signal reception, are concentrated in a specific area, indicating that the transmission power of PCI 201 is significantly high in this region. The concentration of PCI 201 around both buildings suggests potential interference, which could result in decreased service quality and reduced network efficiency.

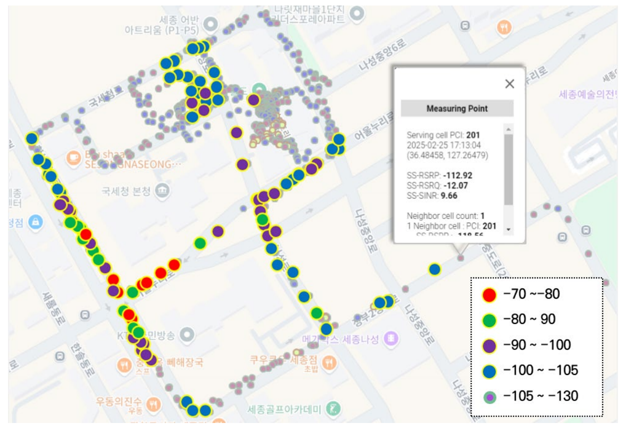

Fig. 6. the signal strength distribution of PCI 201

IV. DISCUSSION

We analyzed and evaluated the potential interference in the target area by examining the PCI distribution based on signal strength in different regions and utilizing GIS maps for visual analysis.

Although the measurement device can receive PLMN IDs, private networks in South Korea do not yet utilize them, making it difficult to directly associate PCI values with specific network operators. Therefore, in this study, we analyzed the signal distribution by matching the each PCI's highest received signal strength to the nearest building. However, this approach may not perfectly reflect the actual deployment of base stations.

Based on the previously analyzed SCMap, PCI 201 is presumed to be transmitted from either Building 1 or Building 2. However, the excessive signal strength observed at specific locations in this figure suggests that the base station at Building 2 may be operating at a higher-than-expected transmission power.

Additionally, in the SCMap, PCI 201 is strongly received around both Building 1 and Building 2. This suggests the possibility that one or both buildings operate base stations using PCI 201. The analysis of the Coverage Map indicates that the coverage areas of Building 1 and Building 2 may partially overlap. If both base stations use the same PCI, it is possible that signals from both stations could be detected simultaneously at certain locations.

In the signal strength data measured for this study, PCI 201 exhibits a pattern where strong signals are concentrated in a specific area. While this may result from a single base station, such a strong signal concentration effect could also occur if two base stations transmit with the same PCI.

However, the current dataset alone is insufficient to confirm with absolute certainty whether both buildings use PCI 201, though the likelihood is high.

If both base stations indeed share the same PCI, it could lead to network operational issues such as PCI collision or PCI confusion. To verify this, further analysis of Neighbor Cell information and signal strength variation patterns at different locations is required.

V. CONCLUSION & FUTURE WORK

A. Conclusion

This study analyzed the coverage and interference characteristics of P5G networks deployed in an urban environment. Through drive tests and signal measurements, we evaluated how P5G base stations interact in a real-world setting, particularly in the context of PCI allocation and interference risks.

The key findings are as follows:

- PCI 201 was observed at both Building 1 and Building 2, indicating a possible PCI overlap between base stations.
- A highly concentrated strong signal area was detected near Building 2, suggesting that the base station's transmission power may be excessively high.
- Potential PCI confusion and interference were identified, which could lead to network degradation.

These results underscore the importance of PCI planning and interference coordination in P5G deployments. Given that e-um 5G networks in South Korea currently lack PLMN IDs, distinguishing network boundaries solely based on PCI remains challenging. Therefore, future work should focus on developing optimized PCI allocation strategies, adaptive transmission power control, and interference mitigation techniques to enhance the performance of P5G networks.

B. Future Work

To further refine interference detection and mitigation, we plan to develop an algorithm that statistically analyzes interference sources, enabling a more precise identification of problematic areas. Additionally, we aim to leverage machine learning techniques on a larger dataset to enhance the accuracy of interference prediction and optimize P5G network deployment. These approaches will contribute to more intelligent and data-driven interference management strategies for future P5G environments.

ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (2021-0-00092, Development of technology for securing and supplying radio resources). (Corresponding author: Kyungyul Cheon)

REFERENCES

[1] 3GPP TR 23.700-07, "Study on enhanced support of Non-Public Networks (NPN),. "

[2] Sang-Yun Lee, “Private 5G (e-Um 5G) Trend and Promotion Policy,” The Journal of Korean Institute of Electromagnetic Engineering and Science, vol. 33, no 7, pp.531-540, Jul. 2022

[3] Ministry of Science and ICT, Korea Communications Agency, "Local 5G guideline," 2021. Available: https://spectrummap.kr/eum5gportal/jointuseAnly/about1

[4] 3GPP TR 36.902, "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network (SON) use cases and solutions." Available: https://www.3gpp.org/ftp/Specs/archive/36_series/36.902/

[5] ITU-R P.1411, “Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz,” Available: https://www.itu.int/rec/R-REC-P.1411/en

[6] 3GPP TR 38.901, “Study on channel model for frequencies from 0.5 to 100 GHz,” Available: https://www.3gpp.org/ftp/Specs/archive/38_series/38.901/

[7] ITU-R P.2109, “Prediction of building entry loss,” Available: https://www.itu.int /rec/R-REC-P.2109/en