Field Trial Report

Outdoor 5G Standalone Network using 28GHz Band – Coverage and Performance

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Version History

Version	Date	Remarks
1.0	16 Jan., 2025	First Release
1.1	24 Jan., 2025	Minor Revision

List of Acronyms and Abbreviations

5G	Fifth Generation Mobile Network / Mobile Services
5GC	5G Core
AAU	Active Antenna Unit
ASTRI	Applied Science and Technology Research Institute
BBU	Baseband Unit
CPE	Customer Premises Equipment
EMBB	Enhanced Mobile Broadband
E.I.R.P	Effective Isotropic Radiated Power
FDD	Frequency Division Duplexing
HKSTP	Hong Kong Science and Technology Park
ISAC	Integrated Sensing and Communication
LOS	Line-of-Sight
MIMO	Multiple-Input-Multiple-Output Antenna
mmWave	Millimeter Wave
NLOS	Non-Line-of-Sight
NSA	Non-standalone
OFCA	Office of the Communications Authority
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
RBS	Radio Base Station
RSRP	Reference Signal Received Power
RTT	Round-Trip Time
QAM	Quadrature amplitude modulation
SA	Standalone
SINR	Signal to Interference & Noise Ratio
TDD	Time Division Duplexing
UE	User Equipment
URLLC	Ultra Reliable Low Latency Communications

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Executive Summary

In Hong Kong, a 5G standalone ("SA") network utilizing the millimeter wave ("mmWave") frequency band is not yet widely available in the commercial market at the time of this report's writing. 5G networks operating in the high-frequency spectrum bands above 24 GHz, offer significantly higher peak data speeds and lower latency compared to those below 6 GHz. As a wholly-owned subsidiary of Asmote in Hong Kong, Shannon & Turing Technology Limited is focused on enabling a 5G mmWave SA network in the region. To achieve this goal, Shannon & Turing Technology Limited/Asmote selected the rooftop of Photonics Center in Hong Kong Science and Technology Park ("HKSTP") and conducted field trial using Asmote's base station, which includes the baseband unit ("BBU") and active antenna unit ("AAU"), as well as user equipment ("UE").

The objective of this field trial report is to present the deployment and performance assessment of a 5G SA private network using mmWave technology in outdoor environments. This field trial report covers 5G SA mmWave network deployment at the rooftop of Photonics Center in HKSTP, along with field measurements conducted evaluate coverage and throughput. The results provided in this technical report focused on the 27.95 – 28.35 GHz mmWave frequency band. The field trial conducted on the 28 GHz frequency band was carried out under Permit No. T00820, granted by the Office of the Communications Authority (OFCA).

The main text of this report summarizes the findings as follows:

- The trial measurement results demonstrated that 5G private network using mmWave frequency band achieved high throughput and low latency in outdoor environments, particularly in Line-of-Sight ("LOS") positions up to approximately 250 meters away, which reflected the typical cell radius for mmWave technology.

- Field measurements demonstrated that, in LOS positions at 50 meters away, the maximum downlink throughput reached 1000 Mbps using a 256 Quadrature amplitude modulation ("QAM") technique with 2 layers, while the maximum uplink throughput reached 80 Mbps with a 64QAM modulation technique and 1 layer. In LOS positions at over 300 meters away, the maximum downlink throughput dropped to 500 Mbps, employing a 64QAM modulation technique and 2 layers, while the maximum uplink throughput was 50 Mbps, utilizing a 16QAM modulation technique with 1 layer. Additionally, the Round-Trip Time ("RTT") at a LOS position located 250 meters away was approximately 6 ms.
- Despite these positive results, challenges such as pathloss and low penetration were also observed in Non-Line-of-Sight ("NLOS") conditions. Nevertheless, the field trials confirmed the feasibility of a 5G SA mmWave network in outdoor environments.

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1 Introduction

1.1 5G in Hong Kong

Commercial 5G services were launched in Hong Kong in April 2020. By November 2022, the subscription of 5G services reached almost 4.4 million. The existing 5G coverage in Hong Kong has reached over 90% of the population, covering all the major business districts, shopping centers and local Mass Transit Railway stations.

5G may operate in non-standalone mode (“NSA”) or standalone (“SA”) mode using frequency ranges below 6 GHz or above 6 GHz to support different deployment scenarios. The choice of frequency bands has a significant impact on the performance and capabilities of the network. Table 1 shows radio characteristics of below 6 GHz band and above 6 GHz band. It is noticed that two frequency bands have different characteristics in terms of coverage, bandwidth, speed, latency, and applications.

Table 1: Radio characteristics of below 6 GHz band and above 6 GHz band.

Frequency Range	**Below 6 GHz**	**Above 6 GHz**
Coverage	Large (Good for wide-area deployment)	Small (Need more base stations to achieve the same size of radio coverage than using frequencies below 6 GHz)
Bandwidth	Small	Large
Speed	High	Very High
Latency	Small	Very Small
Application (Example)	Wider areas such as buildings on both sides of the streets	Hotspots with high subscriber density and data usage such as exhibition venues

1.2 5G Standalone Network Using mmWave Frequency Band

As next breakthrough of 5G network performance, one of the key technologies that will play a crucial role in enhancing the capabilities of 5G is millimeter wave (“mmWave”) SA network. Table 2 outlines the 26/28 GHz band allocation[1] to different mobile network operators (“MNOs”). It shows that the

[1] Refer to Office of the Communications Authority - Press Releases (Record No.: 2350)

frequency range of 25.55 – 27.95 GHz has been designated for mobile network operators ("MNOs") to provide public mobile service. Furthermore, the frequency range of 27.95 – 28.35 GHz is available for assignment on a geographically shared basis, allowing individual entities to apply to establish their own 5G SA networks.

Table 2: The 26/28 GHz band allocation to different mobile network operators.

Assignee	Frequency Range (GHz)	Amount (MHz)
China Mobile Hong Kong Company (CMHK) Limited	26.15 – 26.75	600
Hong Kong Telecommunications (HKT) Limited	27.35 – 27.95	600
Hutchison Telephone Company Limited (HTCL)	25.55 – 26.15	600
SmarTone Mobile Communication Limited	26.75 – 27.35	600

Many 5G applications, such as Enhanced Mobile Broadband ("eMBB"), Ultra Reliable Low Latency Communications ("URLLC"), rely on the advanced performance of 5G SA mmWave network which is not yet widely available in the commercial market. These networks operate in the high-frequency spectrum bands above 24 GHz, offering significantly higher peak data speeds and lower latency as compared to current 5G networks.

Towards 6G, mmWave SA networks are considered suitable for enabling integrated sensing and communication ("ISAC") use cases, where wireless networks are used not only for data communication but also for sensing and monitoring various environmental parameters.

1.3 About Shannon & Turing Technology Limited and the Trial

Asmote is a technology innovation company with a focus on wireless technology, led by a core team with extensive experience in the wireless industry. The team has been actively involved in driving the evolution of global wireless technology, playing key roles in the development of 5G initiatives, industry alliances, and cutting-edge wireless products. Shannon & Turing Technology Limited is wholly-owned subsidiary of Asmote in Hong Kong.

Shannon & Turing Technology Limited/Asmote intends to enable a 5G mmWave SA network in Hong Kong. To this end, Shannon & Turing Technology Limited/Asmote chooses the rooftop of Photonics Center in HKSTP to conduct field trial using ASTRI's 5G Core ("5GC"), Asmote's base station including BBU and AAU, and user equipment. The field trial of radio sensing will be conducted using Asmote mmWave radio units.

1.4 Objectives and Organization of this Study Report

In this report, Photonics Center is selected as the trial site, and a 5G SA mmWave private network is deployed at the rooftop of Photonics Center, with one 5GC server, one BBU, and one AAU, operating on 27.95 – 28.35 GHz frequency band. The field trial conducted on the 28 GHz frequency band was carried out under Permit No. T00820, granted by OFCA. Field measurements were conducted outside the Photonics Center in HKSTP, to evaluate the performance including coverage and throughput. This report is divided into the following sections:

- Section 2 provides the trial design and 5G SA private network deployment;
- Section 3 outlines test cases and test equipment. The measurement results including coverage, throughput and Ping latency are presented; and
- Section 4 sums up the findings of this study.

2 Trial Design and 5G SA Private Network Deployment

In this section, trial site information is introduced first, then network parameters of 5G outdoor system are presented, followed by the 5G SA private network deployment at trial site.

2.1 Trial Site Information

Shannon & Turing Technology Limited/Asmote conducted the field trial of a 5G SA mmWave network deployment using ASTRI's 5GC, Asmote's base station including BBU and AAU, and user equipment. The root top of Photonics Center was chosen as the trial site. Its basic information is shown in Table 3.

Table 3: Site name, address, and coordinate information.

Site	Information
Name	Photonics Centre
Address	Rooftop, 2 Science Park East Avenue, Hong Kong Science Park, Shatin, Hong Kong
Coordinate Information	Northing (m), Easting (m): 831630, 840111 Latitude (N), Longitude (E): 22.42402, 114.2142

The 5G base station was installed at the rooftop of Photonics Centre with antenna height of 39 meters, azimuth of 340 degrees and down tilt of 15 degrees. The details of the antenna position and direction are listed in Table 4. Figure 1 shows the site location on the map.

Table 4: Antenna position and direction.

Parameter	Value
Antenna Height (m)	39
Bearing (°)	340
Down-tilt (°)	15

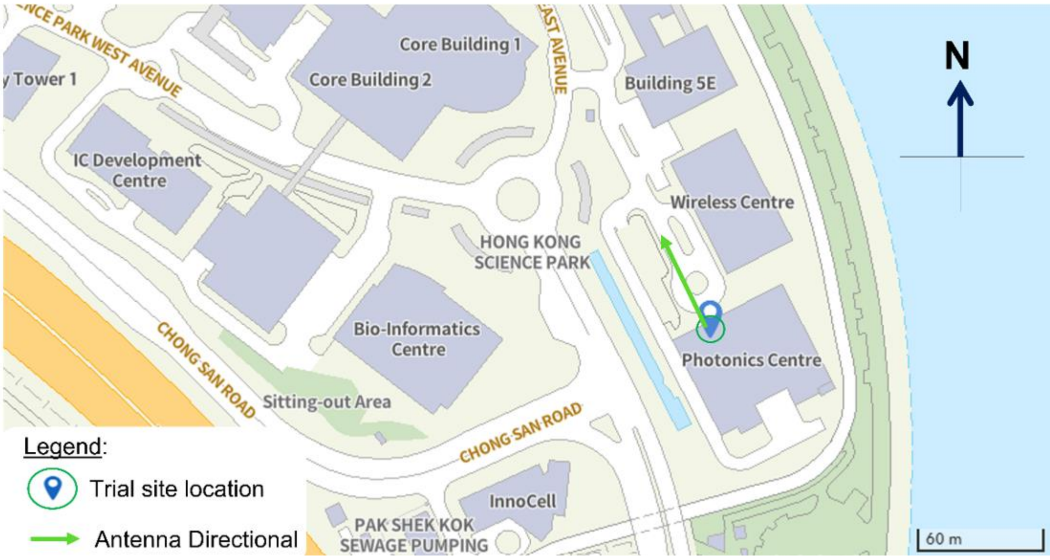


Figure 1: Site location on the map and direction of AAU.

2.2 Parameters of 5G Outdoor System

The 5G outdoor cell operates within the 27.95 – 28.35 GHz frequency band. During the measurement process, only a single carrier was utilized, resulting in a carrier bandwidth of 200 MHz. The maximum transmit power per carrier is 10 Watts (i.e., 40 dBm) effective isotropic radiated power ("EIRP"). Table 5 provides a summary of the configuration parameters for the 5G outdoor cell. Time Division Duplex ("TDD") mode was employed, featuring a downlink to uplink ratio of 4:1, consistent with the parameters set by the MNOs.

Table 5: Configuration parameters of a 5G outdoor system.

Parameters	Value	Remark
Number of Carriers	1	
Transmit Power per Carrier (dBm)	40	1 carrier @ 40dBm
Carrier Frequency (GHz)	27.95 – 28.35	
Carrier Bandwidth (MHz)	200	
TDD or FDD	TDD	
Downlink/Uplink Ratio	4:1	TDD mode
Aggregated Power from Power Amplifier (dBm)	23	
Multiple-Input and Multiple-Output (MIMO) Configuration	2 x2 MIMO	
Maximum Antenna Gain (dBi)	17	
Maximum EIRP (dBm)	40	10 Watts

2.3 5G SA Private Network Deployment

5G private network deployment involves the installation of 5G base stations, antennas, and related equipment to provide wireless coverage and connectivity to users. Figure 2 shows 5G network architecture design. The deployment includes one ASTRI's 5GC server, one Asmote's BBU and one Asmote's AAU. Figure 3 shows the locations of 5G main equipment and antennas at rooftop of Photonics Center.

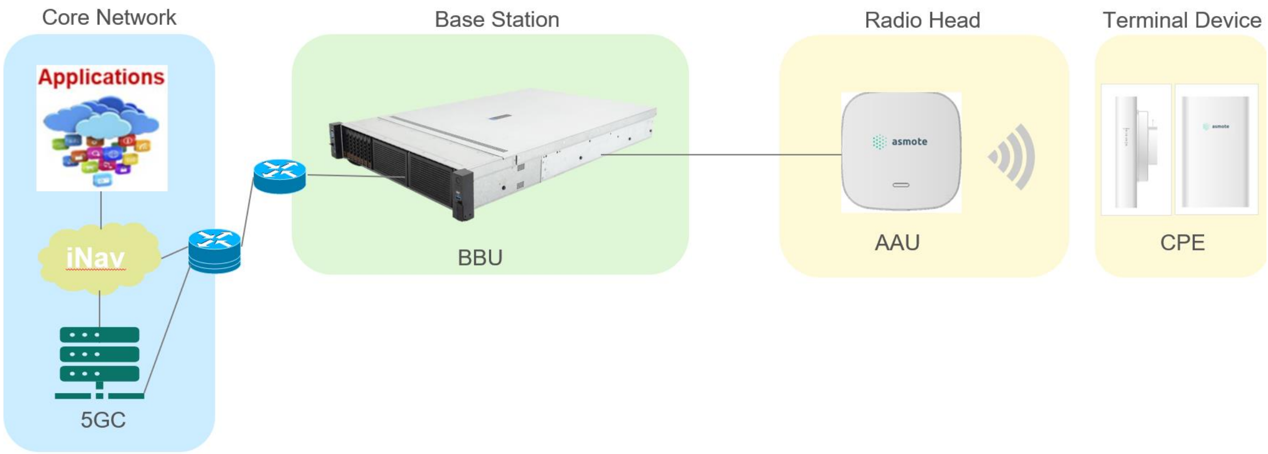


Figure 2: 5G Network architecture design.

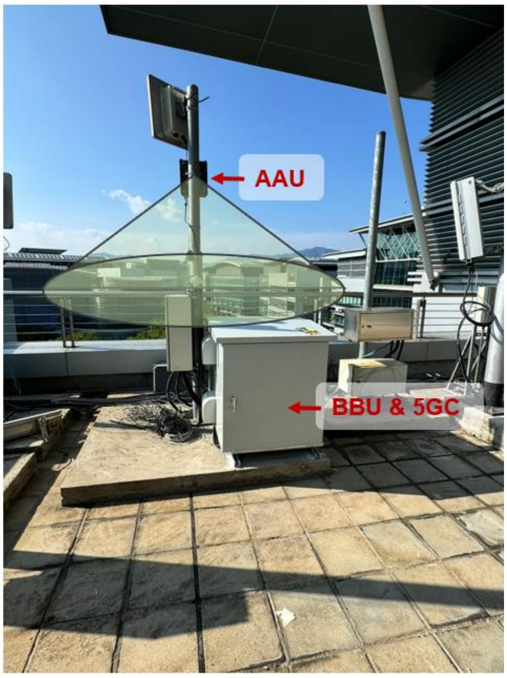


Figure 3: locations of 5G main equipment and antennas at rooftop of Photonics Center.

Figure 4 shows the direction of the antenna's main beam and Figure 5 shows 3D map of science park within the coverage the main beam. It is noticed that many trees with dense foliage and structures like buildings, foot bridges, bus shelters, and covered walkways along the main road. These obstructions have the potential to block the signal between the UE at ground level and the base station located on the rooftop.

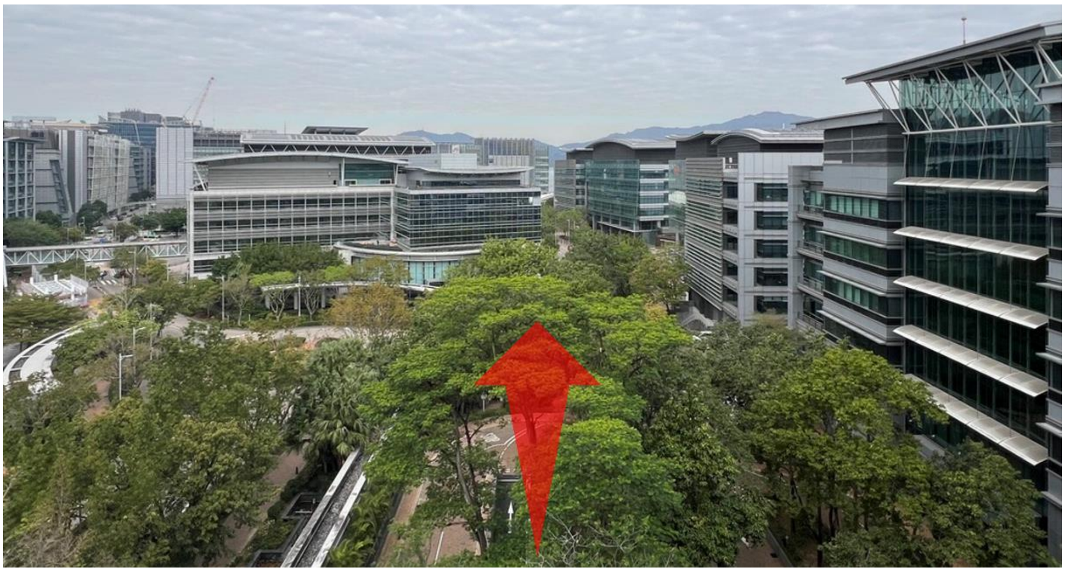


Figure 4: Direction of the antenna's main beam.

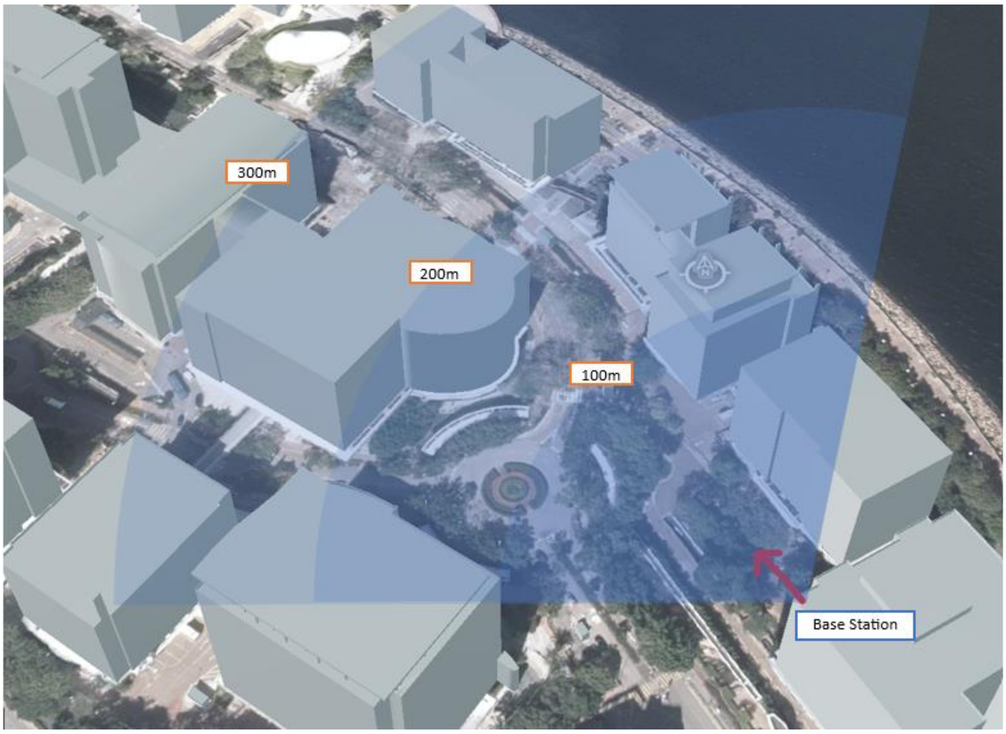


Figure 5: 3D map of the areas in HKSTP within the coverage of the antenna's main beam.

3 Measurement Results on Coverage and Throughput

Field measurements were carried out to assess the performance of the 5G outdoor private network, focusing on both coverage metrics such as Reference Signal Received Power ("RSRP") and Signal Interference Noise Ratio ("SINR") and throughput evaluation.

3.1 Test Cases and Test Equipment

Table 6 outlines the test cases and test equipment. The 5G network measurement equipment includes the software of DingLi Pilot Pioneer (version 10.5), and the hardware of Asmote iNode9122 5G Outdoor Customer Premises Equipment ("CPE").

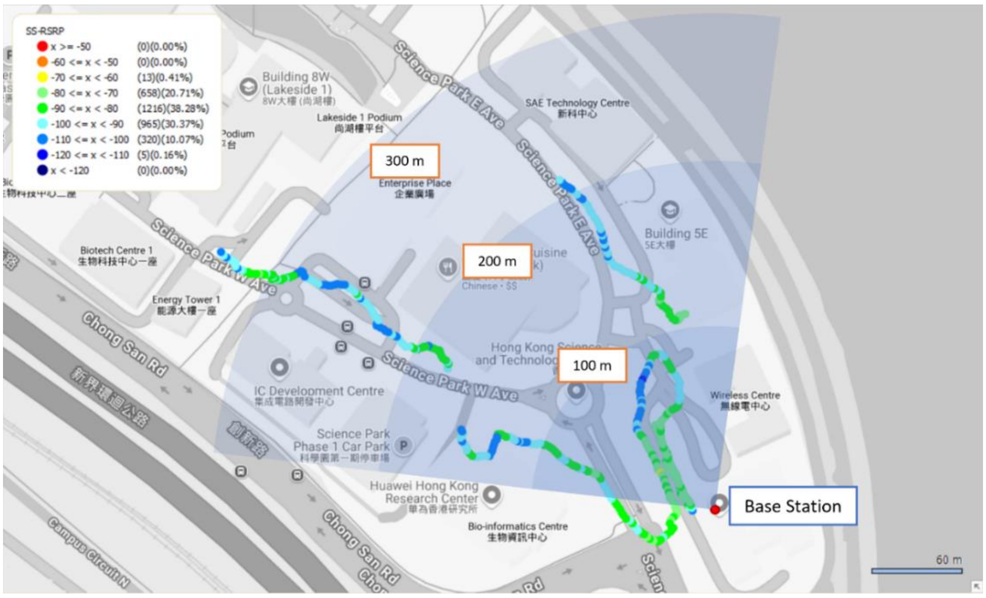
Table 6: Test cases and equipment information

Test Cases	Test Equipment	Type
Coverage test (SA) Throughput test (SA)	DingLi Pilot Pioneer (V10.5)	Software
	Asmote iNode9122 5G Outdoor CPE	Hardware

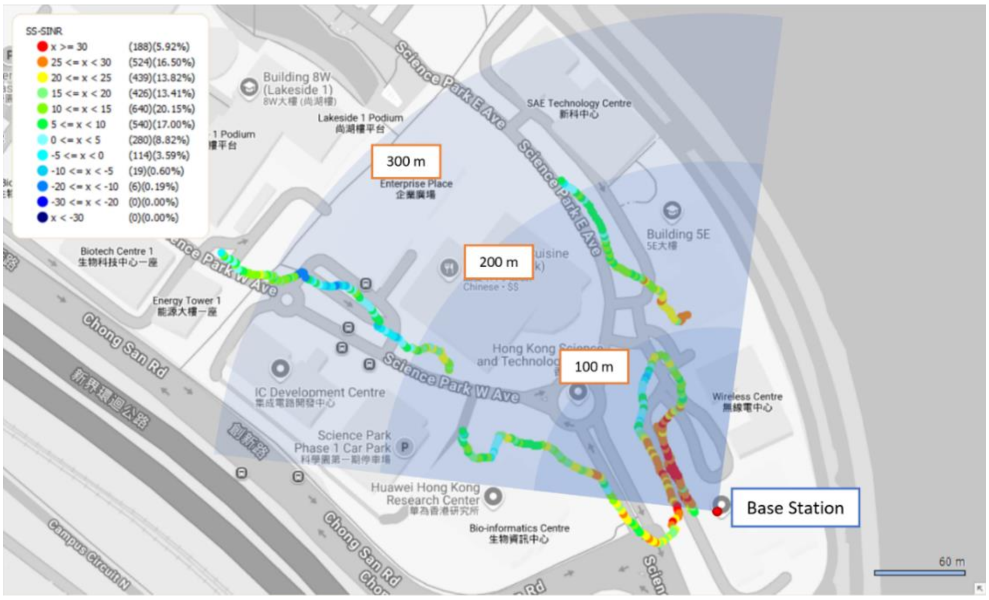
Field measurements of 5G coverage and throughput were conducted using a heatmap analysis. This involves collecting data on signal strength and throughput at various locations within the coverage area and mapping this data onto a geographical map to visualize the coverage and performance of the 5G network. Advantages of using a heatmap analysis for field measurements of 5G coverage and throughput include a) visual representation; and b) comprehensive coverage analysis. In this section, a heatmap analysis is used to evaluate the performance of 5G in terms of coverage and throughput.

3.2 Coverage Results

Field measurements on coverage were performed along two roads: Science Park West Avenue and South Science Park East Avenue. Figure 6 (a) and (b) illustrate that in both directions, the RSRP and SINR weaken as the distance from the base station increases. On Science Park West Avenue, the maximum coverage extends beyond 300 meters from the base station when there is a clear LOS. In contrast, on Science Park East Avenue, the maximum coverage reaches just over 200 meters from the base station under clear LOS conditions, primarily due to dense foliage and obstacles that hinder the signal between the UE and the base station.



(a) RSRP



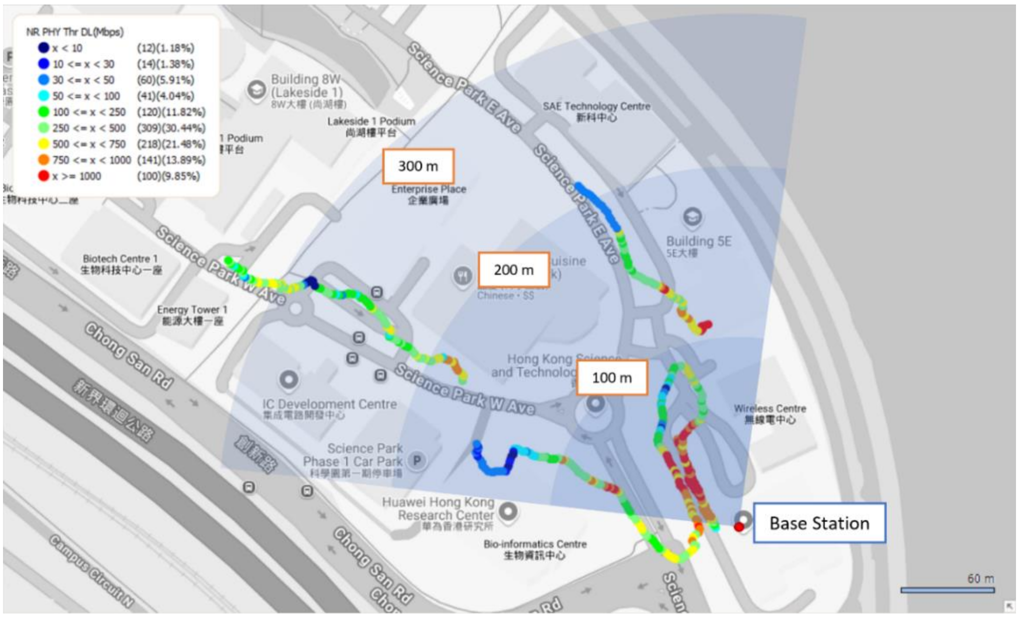
(b) SINR

Figure 6: Measurement results of (a) RSRP; and (b) SINR.

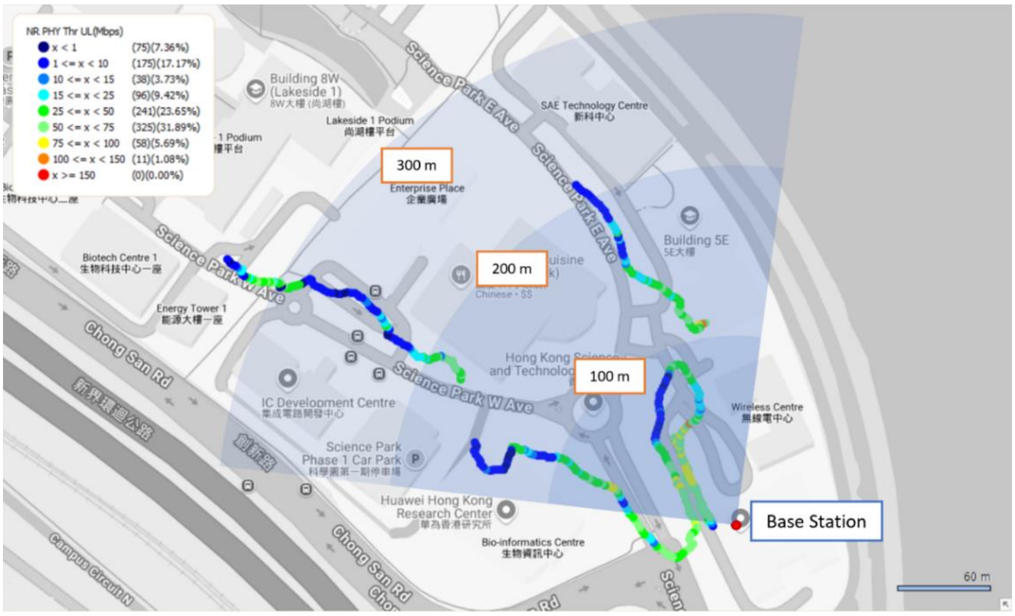
Figure 6 (a) indicates that approximately 38.3% of the test routes has RSRP values between [-90 dBm, -80 dBm], while around 30.4% falls within the range of [-100 dBm, -90 dBm]. Figure 6 (b) shows that approximately 16.5% of the test routes falls within the range of [10 dB, 15dB], and about 20.1% experiences SINR values between [25 dB, 30 dB].

3.3 Physical Layer (“PHY”) Throughput Results

PHY throughput refers to the data transfer rate measured at the physical layer, which includes the raw bit rate that can be transmitted over the air interface, accounting for modulation schemes, coding rates, and other physical layer parameters.



(a) Downlink



(b) Uplink

Figure 7: Measurement results of PHY throughput; (a) downlink and (b) uplink.

Figure 7 (a) and (b) show that approximately 30.4% of the test routes have PHY downlink throughput within the range of [250 Mbps, 500 Mbps], while around 31.9% of the routes achieve PHY uplink throughput between [50 Mbps, 75 Mbps].

The maximum PHY throughput were also recorded at various test points where there is a clear LOS from the base station to the test locations. Table 7 shows that at a distance of 50 meters, the maximum PHY downlink throughput achieves 1000 Mbps using a 256QAM modulation technique with 2 layers. In contrast, the maximum PHY uplink throughput reaches 80 Mbps with a 64QAM modulation technique and 1 layer. At the furthest test point, located over 300 meters from the base station, the maximum PHY downlink throughput drops to 500 Mbps, employing a 64QAM modulation technique and 2 layers, while the maximum PHY uplink throughput is 50 Mbps, utilizing a 16QAM modulation technique with 1 layer.

Table 7: Maximum PHY throughput results at different test points.

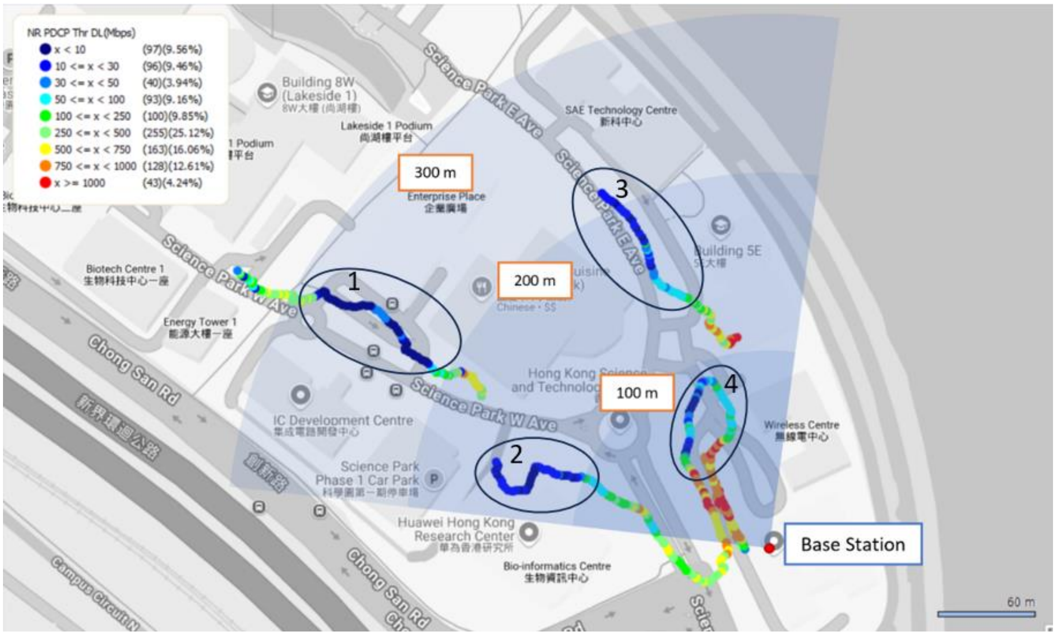
PHY Throughput	Clear Line-of-Sight from base station to test point	
	50 meters away	300 meters away
Downlink	1000 Mbps @256QAM with 2 layers	500 Mbps @64QAM with 2 layers
Uplink	80 Mbps @64QAM with 1 layer	50 Mbps @16QAM with 1 layer

3.4 Packet Data Convergence Protocol ("PDCP") Throughput Results

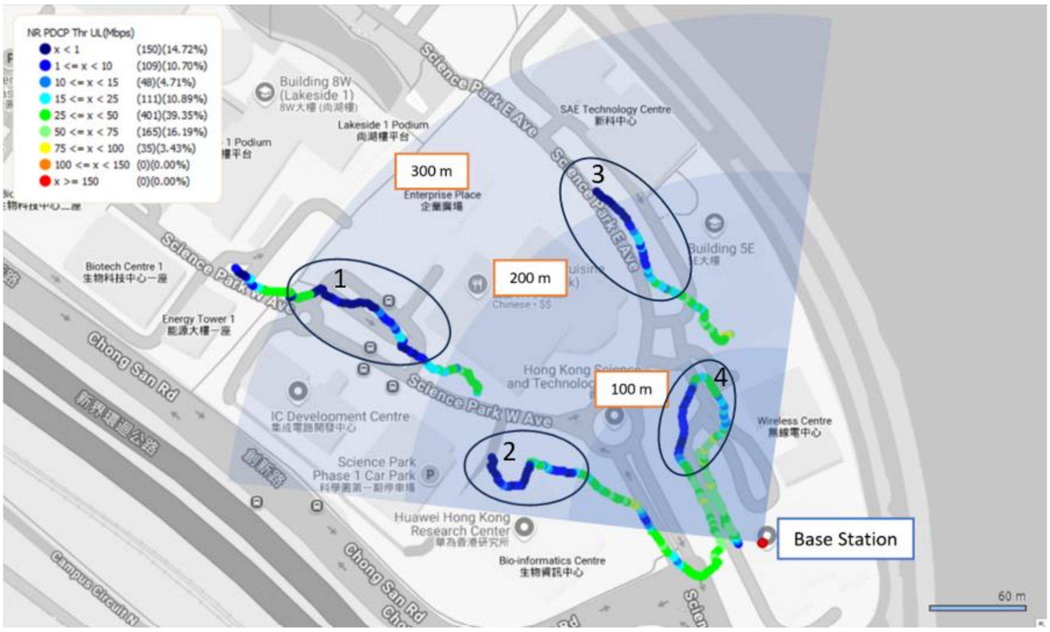
Besides PHY throughput, PDCP throughput was also measured. PDCP throughput is measured at the PDCP layer, which is responsible for header compression, encryption, and segmentation of data packets. PDCP throughput reflects the effective data rate after processing by the PDCP layer.

Unlike PHY throughput, PDCP throughput focuses the actual user data transmitted after accounting for protocol overhead and processing, offering a clearer insight into the data available for applications.

Figure 8 (a) and (b) show that approximately 25.1% of the test routes achieves PDCP downlink throughput in the range of [250 Mbps, 500 Mbps], while around 39.4% experiences PDCP uplink throughput between [50 Mbps, 75 Mbps].



(a) Downlink



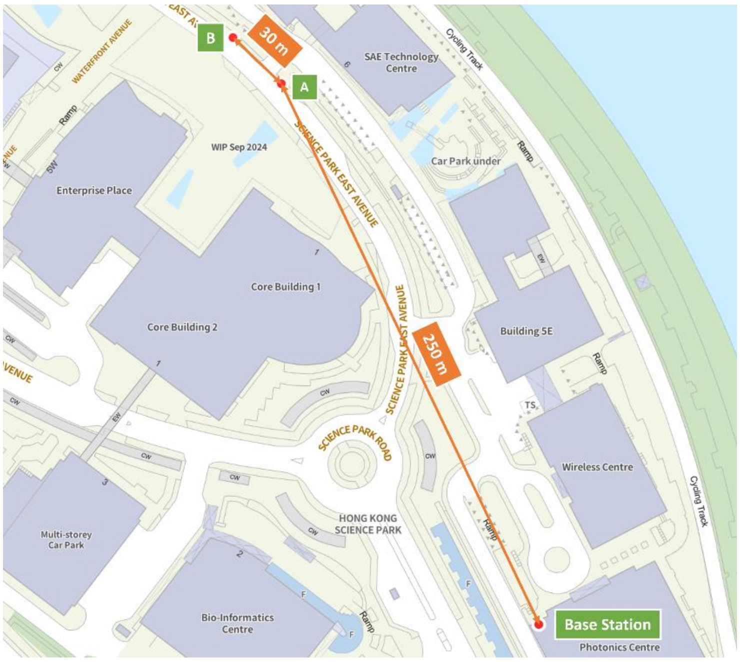
(b) Uplink

Figure 8: Measurement results of PDCP throughput (a) downlink; and (b) uplink.

Figure 8 (a) and (b) also show that the PDCP throughput deteriorates significantly in non-line-of-sight (NLOS) areas. As compared with Figure 7, a substantial difference between the two throughputs is observed, suggesting potential issues in data processing or transmission, such as excessive retransmissions due to poor SINR. The reason is that areas 1 and 2 are obstructed by a foot bridge, while areas 3 and 4 are hindered by dense foliage from trees (which can be noticed in Figure 4). Conversely, on test routes with clear LOS, PDCP throughput closely aligns with PHY throughput.

3.5 Latency Results

A Ping test was conducted starting from the original test point A, as illustrated in Figure 9 (a) and Figure 9 (b). Test point A was located approximately 250 meters from the base station, near the edge of coverage but still maintaining a clear LOS. The UE was then slowly moved to point B, as shown in Figure 9 (b) and Figure 9 (c), which was approximately 280 meters from the base station. At this location, the connection was Non-Line-of-Sight (“NLOS”) due to obstruction by foliage. Finally, the UE was gradually returned to the original test point A before disconnecting from the network.

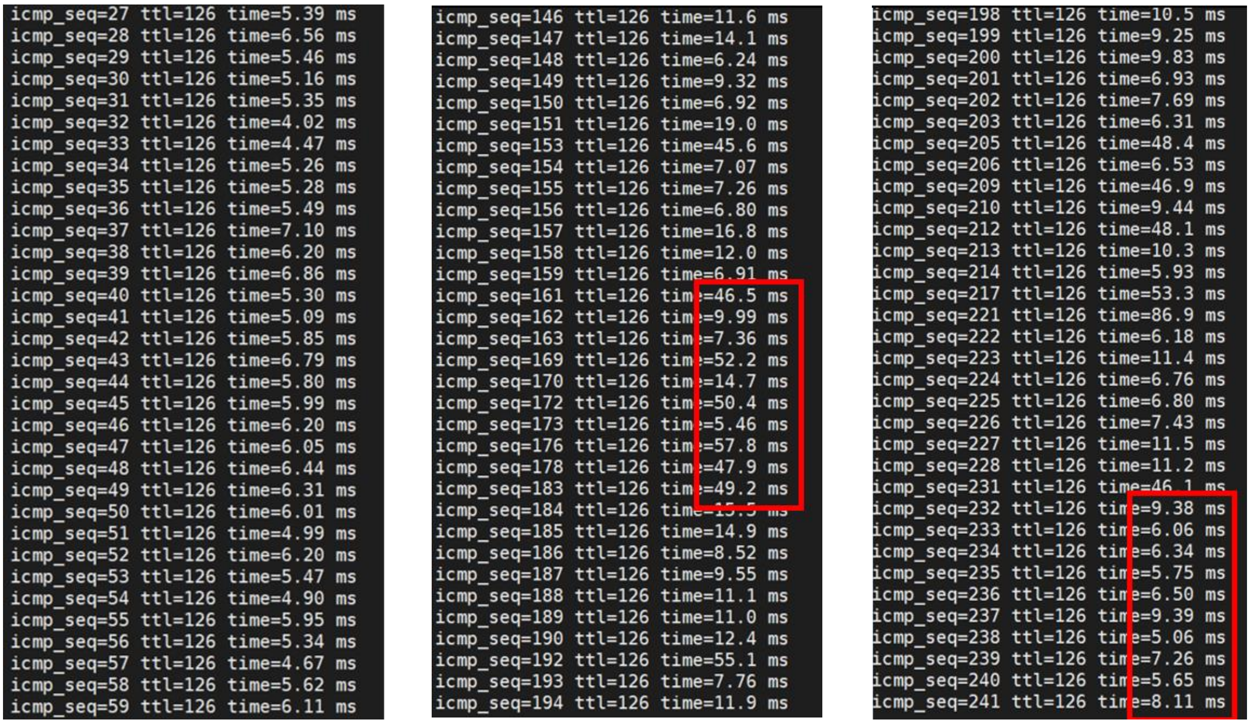


(a)

(b) (c)

Figure 9: Ping test is conducted at test points A and B (a) Test points A and B on the map; (b) UE at the original test point A; and (c) UE at the test point B.

Figure 10 presents the results for Ping latency. In Figure 10 (a), the RTT at the original test point A is approximately 6 ms. Figure 10 (b) illustrates that as the UE moves from A to B, the Ping latency gradually increases to over 50 ms due to the UE's mobility and obstruction of the LOS path. In Figure 10 (c), as the UE returns from B to A, the Ping latency slowly decreases to below 10 ms.



(a) (b) (c)

Figure 10: Ping latency results (a) at original test point A; (b) UE is moving from A to B; and (c) UE is moving back from B to A.

4 Conclusion

The deployment of a 5G SA private network utilizing the 27.95 - 28.35 GHz mmWave frequency at the rooftop of the Photonics Center has been successfully accomplished and thoroughly tested. This report provided the deployment design and performance evaluation of the 5G SA mmWave network. The results provided in this technical report focused on the 27.95 – 28.35 GHz frequency band. The main conclusions are described in the following paragraphs.

- When 5G mobile signal using 27.95 – 28.35 GHz frequency band is transmitted at the rooftop, and the antenna transmitting power is set to less than or equal to 10 Watts (i.e., 40 dBm) EIRP, a high-quality coverage and throughput performance as well as low latency can be effectively achieved at LOS positions, even at distances of approximately 250 meters.
- Field measurements showed that in LOS positions 50 meters away, the maximum downlink throughput achieved 1000 Mbps using a 256QAM modulation technique with 2 layers, while the maximum uplink throughput reached 80 Mbps using a 64QAM modulation technique and 1 layer. However, at LOS positions beyond 300 meters, the maximum downlink throughput decreased to 500 Mbps with a 64QAM modulation technique and 2 layers, while the maximum uplink throughput was 50 Mbps with a 16QAM modulation technique and 1 layer. Furthermore, the RTT at a LOS position situated 250 meters away was approximately 6 ms.
- 5G SA mmWave technology also encountered challenges such as pathloss and limited penetration, especially noticeable in NLOS conditions, as indicated by the test results. Despite these obstacles, the field trials validated the feasibility of a 5G SA mmWave network, fostering the adoptions of 5G SA private networks using mmWave frequency band for vertical applications in Hong Kong.
- The field trial will contribute to scientific research in ISAC, 6G technologies, and other innovative wireless advancements. Shannon & Turing Technology Limited/Asmote is playing

a pivotal role in developing advanced wireless solutions and promoting technological progress in Hong Kong’s wireless ecosystem, ultimately benefiting the region’s 5G market.