Technology Reports

NR | Radio Wave Visualizer | Channel Sounding

Radio Wave Visualizer for 5G Area Optimization
—Real-time Radio Wave Visualizer for 3GPP—

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The wavelengths of the high-frequency bands being considered for use with 5G are much shorter than those used previously, and these bands are much more affected by people, vehicles, and other objects in the vicinity of terminals such as mobile phones. NTT DOCOMO has developed equipment that uses a head-mounted display to provide a visualization of fluctuations in the state of arriving signals due to such effects. The equipment provides a 360° real-time visualization of signals from a 3GPP compliant base station, and can be used to facilitate efficient positioning of base stations, orientation of antennas, and optimization of cell areas.

1. Introduction

The 3rd Generation Partnership Project (3GPP)*1 has created the New Radio (NR) specification [1] that will enable the requirements for 5th Generation mobile communication systems (5G) to be realized, and mobile telephone operators around the world are now working hard to introduce 5G services.

With 5G, high-frequency bands of 6 GHz and higher are expected to be used to secure wider bandwidth and realize the high speed and capacity of enhanced Mobile BroadBand (eMBB) [2]–[4]. Other technologies are also being studied to implement Ultra-Reliable and Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC), which will accommodate large numbers of Internet of Things (IoT) terminals.

As part of this work, radio propagation characteristics*2 in various user environments need to be understood so that NR areas can be optimized, and the new high-frequency bands have extremely short

*1 3GPP: An organization that creates standards for mobile communications systems.

*2 Radio propagation characteristics: Refers to characteristics such as propagation losses, power and delay profiles, and angular profiles.

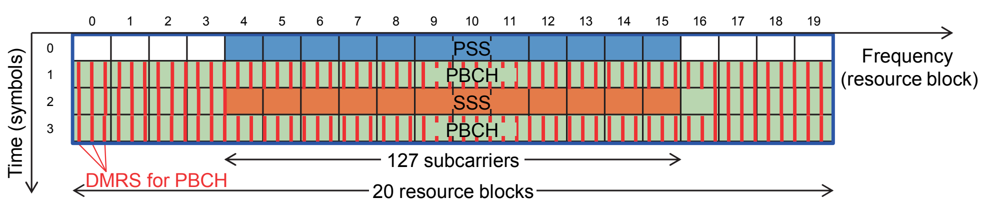
wavelengths and are affected by objects such as people and buildings surrounding mobile phones and other terminals. This can cause fading in the signals arriving from base stations. To make it easier to understand such fluctuations, NTT DOCOMO developed a real-time radio wave visualizer that could show the state of radio waves arriving from directions spanning 360°, which was partially completed in May 2018 [5]. Although this equipment was designed to support 360° visualization of signals, expanded from the initial range of 180°, it also needs to support the visualization of NR signals in order to receive signals from NR-conforming base stations. Therefore, the required visualization has not yet been achieved.

Then, in November of that year, NTT DOCOMO used a new NR-signal channel sounding[*3] function to develop its 3GPP real-time radio wave visualizer, to visualize radio waves from NR conforming base stations in real time. By using Augmented Reality (AR)[*4] technology, this equipment can visualize the arrival state of radio waves as they fluctuate from one minute to the next, and can be used to facilitate installation and configuration of base stations, and optimization of cell areas.

This article describes the system architecture of the equipment, along with an implementation example.

2. Channels for Radio Wave Visualization

This equipment uses the NR SS/PBCH Block (SSB)[*5] to recognize signals from each base station and visualize them. The SSB structure is shown in **Figure 1**. NR uses Orthogonal Frequency Division Multiplexing (OFDM)[*6], and this consists of Synchronization Signals (SS)[*7]: a Primary SS (PSS)[*8]



SSB subcarrier interval	SSB transmission bandwidth
15 kHz	3.6 MHz
30 kHz	7.2 MHz
120 kHz	28.8 MHz
240 kHz	57.6 MHz

Figure 1 SSB structure

*3 Channel sounding: Measurement of propagation channel characteristics such as path losses, delay profile, and angular profile.

*4 AR: A technology that superposes digital information on video of the real world such that it actually appears to be part of the scene to the user.

*5 SSB: Component including SS (see *7) and Physical Broadcast CHannel (PBCH), which is transmitted periodically. Terminals receive it for not only detecting cell ID and reception timing but also performing measurement of the cell quality.

*6 OFDM: A multi-carrier modulation format where information signals are modulated with orthogonal subcarriers.

*7 SS: A physical signal that enables detection of the synchronization source identifier (cell ID etc.), and frequency and reception timing required by the mobile terminal to start communications.

and a Secondary SS (SSS)*9; a Physical Broadcast CHannel (PBCH), and the DeModulation Reference Signals for the PBCH (DMRS for PBCH)*10. Also, NR is composed of slots*11, subframes*12, and frames*13 made up of multiple OFDM symbols*14. Slots are composed of 14 OFDM symbols, regardless of the subcarrier*15 interval, frames are composed of 10 subframes, and the frame length is 10 ms. In this case, the timing of SSB transmission is in half of a frame, with length of 5 ms. **Figure 2** shows an example of SSB transmission structure when transmitting 64 SSBs with SSB transmission period of 20 ms and subcarrier interval of 120 kHz. As the figure shows, when transmitting SSBs, multiple SSBs are transmitted, each in different beams.

3. System Architecture for Visualizing Radio Waves

3.1 System Architecture

An example system architecture for this equipment is shown in **Figure 3**. The equipment uses a 360° camera, a multi-element array antenna*16, a channel sounder, and a PC to visualize signals arriving from base stations in real time. Signals emitted from base stations are received by the multi-element array antenna, channel estimation*17 is performed, and then the channel sounder analyzes the

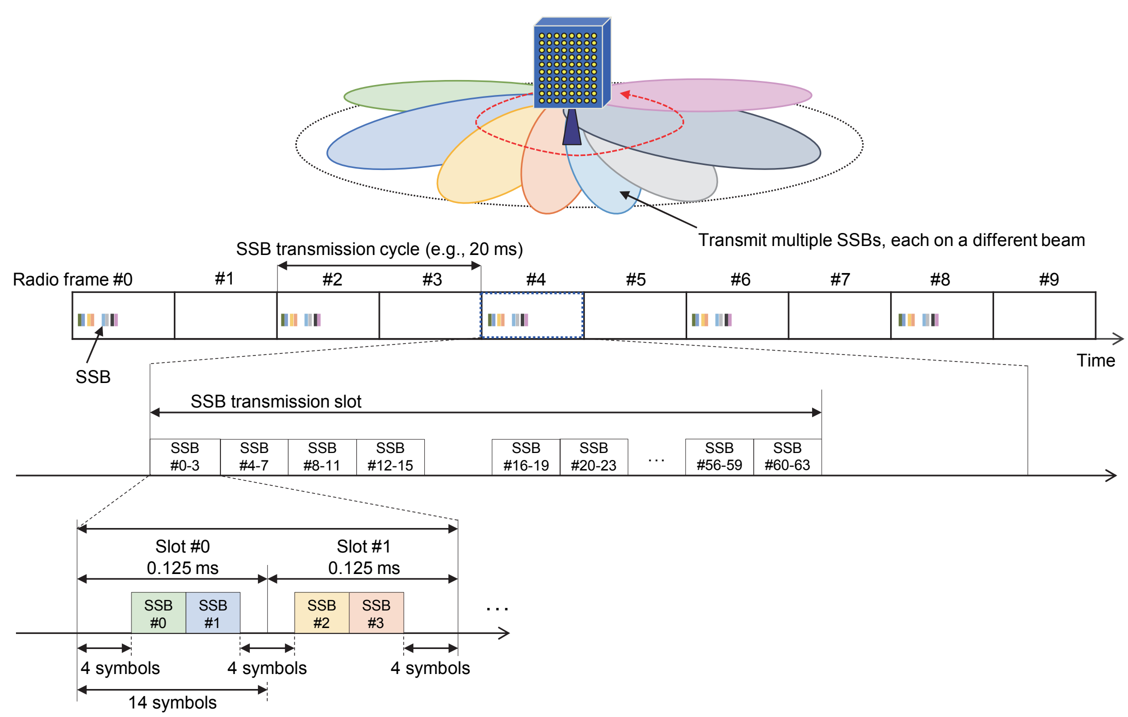


Figure 2　Example of an SSB transmission structure

*8　**PSS:** A known signal that the user equipment first searches for in the cell search procedure.

*9　**SSS:** A known signal transmitted to enable detection of the physical cell ID in the cell search procedure.

*10　**DMRS for PBCH:** A known signal transmitted to measure the state of a radio channel for PBCH demodulation.

*11　**Slot:** A unit for scheduling data consisting of multiple OFDM symbols.

*12　**Subframe:** A unit of radio resources in the time domain, consisting of multiple slots.

*13　**Frame:** The period in which an encoder/decoder operates or a data signal of length corresponding to that period.

*14　**Symbol:** The unit of data transmission.

*15　**Subcarrier:** Each carrier in a multi-carrier modulation system that transmits bits of information in parallel over multiple carriers.

delay and angular profiles*18 of the arriving signals. The channel sounder function has a radio unit and a channel sounding unit. The PC performs image processing to integrate the results of this analysis with the video from the 360° camera and outputs it to the display.

3.2 Functional Architecture

The functional architecture is shown in **Figure 4**. To perform channel estimation, multiple SSBs emitted on different beams must be received and the SSB transmission timing detected. The radio unit*19 receives the signals from the multi-element array antenna, converts them to an Intermediate Frequency (IF)*20, and computes the correlation*21 with the SS to detect the timing that maximizes correlation. Based on the detected SSB transmission timing, the channel estimation result is computed, which is a matrix of 127 SS subcarriers by N array antenna elements. An Inverse Fast Fourier Transform (IFFT)*22 is then used to compute the delay profile. An anechoic chamber*23 is used to estimate channels for each arrival angle beforehand, and these are used to calibrate measurement

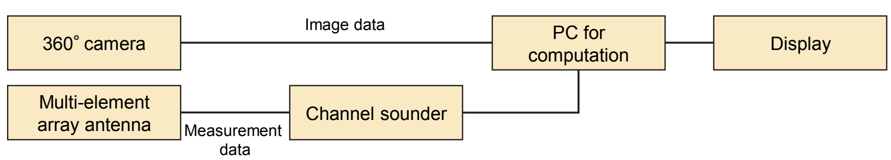


Figure 3 System architecture

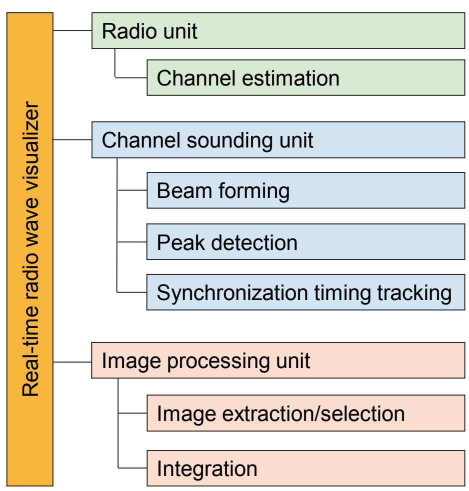


Figure 4 Functional architecture

*16 Array antenna: An antenna consisting of an array of multiple antenna elements.

*17 Channel estimation: Estimation of changes in parameters such as amplitude and phase as a signal traverses a radio channel.

*18 Delay and angular profiles: A waveform representing the relationships between propagation delay and received power for direct signals, reflected signals, and diffused signals arriving at the receiving station is called the delay profile, and that representing the relation between arrival angle and received power is called the angular profile.

*19 Radio Unit: Equipment that converts the received digital signal to an intermediate frequency, amplifies the received signal, receives the signals from antenna elements and other functions.

data for beam forming*24.

The channel sounding unit then performs synchronization timing tracking to enable stable angular-profile peak detection and channel sounding, which is used to define the beam forming and signal arrival angles. First, beam forming is done by computing the correlation between the analyzed delay profiles and correction data estimated beforehand, and then delay-angular profiles are computed for each arrival angle. Reception levels are then computed for each arrival angle from these results, peak detection is done to define the arrival angles, and this yields results indicating the angular profiles and arrival directions.

Finally, the image processing unit extracts image data for each of the arrival angles from the 360° camera video, and integrates it with the computed angular profiles obtained by the channel sounding unit to visualize the states of arriving signals.

4. Implementation

The equipment was implemented with a radio unit, a channel sounding unit, a PC, and a Head-Mounted Display (HMD)*25 (**Figure 5**). The radio unit consists of a 28 GHz cylindrical array antenna with 256 elements, arranged on 8 levels vertically, and in 32 directions around a circle, and a radio-frequency front-end. The PC is used to integrate image data with the channel sounding data, and the HMD provides a way to understand the 360° signal arrival state efficiently. A maximum of four channels can be received and the maximum number of antenna elements per channel is 64. The cylindrical array antenna was used so that signals

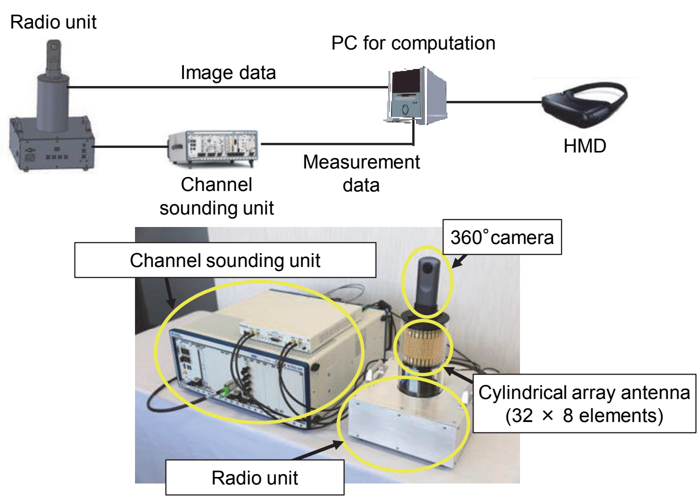


Figure 5 Example system implementation

*20 IF: A frequency that is lower than the carrier frequency. In most wireless communication systems, the baseband transmission signal is first converted to an intermediate frequency rather than being modulated directly to the carrier frequency (or the received signal is directly demodulated to the baseband signal).

*21 Correlation: An index expressing similarity between different signals. Expressed as a complex number, its absolute value ranges from 0 to 1. Similarity is higher for a value closer to 1.

*22 IFFT: A fast algorithm for converting discrete frequency domain data into discrete time domain data.

*23 Anechoic chamber: A test facility that is shielded from external radio waves and where the walls, floor and ceiling are covered with an electromagnetic absorbing material to suppress reflections.

arriving from a 360° range of angles can be visualized. For NR, SSB subcarrier intervals are specified to be 15 kHz, 30 kHz, 120 kHz, or 240 kHz and the number of subcarriers is fixed, so the transmission bandwidths for each subcarrier interval are different. As such, the equipment was made to support a maximum analysis bandwidth of 80 MHz, as shown in **Table 1**.

As shown in **Figure 6**, channel estimation is implemented in the radio unit using a Field Programmable Gate Array (FPGA)*26. Beam forming, peak detection and synchronization timing tracking are implemented in the channel sounding unit using FPGA and software. An FPGA was used to accelerate beam forming because it is computationally intensive, and peak detection and synchronization timing tracking are implemented in software. The image processing unit is implemented using the PC Graphics Processing Unit (GPU), and integrates the estimation data with image data, which is selected based on the orientation of the HMD being worn by the user.

Table 1 Equipment specifications

Item	Specification
Frequency band	28 GHz
Maximum bandwidth	80 MHz
Antenna	256 elements/32-sided cylindrical array antenna
Channels used	5G NR SSB

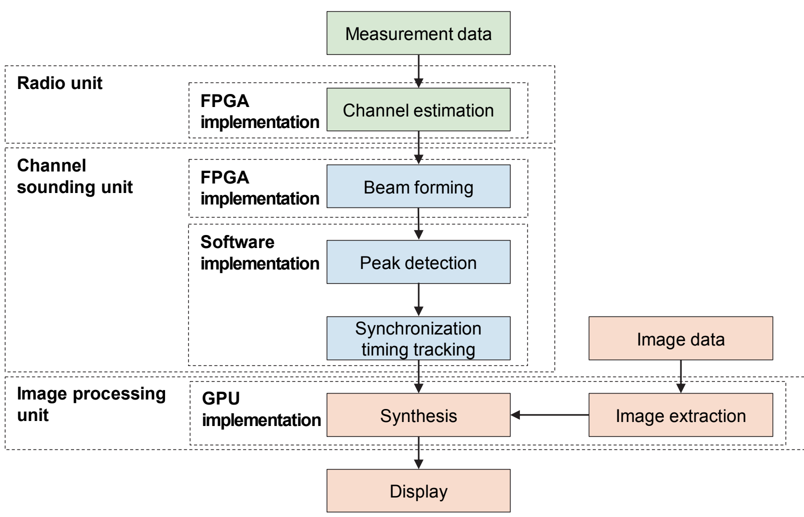


Figure 6 Implementation flow chart

*24 Beam forming: A technology that uses multiple antenna elements to give directionality to signals radiated or received by the antenna.

*25 HMD: Display equipment which is worn on the head, in the form of goggles or a helmet, with small display screens positioned directly in front of the eyes. There are monocular types, which display an image for only one eye, and binocular types, which display images for both eyes.

*26 FPGA: A large-scale integrated circuit capable of being re-written, consisting of cells arranged in the shape of an array and wiring elements.

A timing chart for channel estimation, beam forming, and peak detection is shown in **Figure 7**. To receive signals from each of the directions properly, elements of the cylindrical array antenna in each direction are used, switching antenna elements while computing correlation with the SS to detect the timing of SSB transmission. The detected SSB transmission timing is used to estimate channels, computing results of beam forming for all antenna elements while switching every four elements in the cylindrical array antenna, so that the arrival state can be visualized over a 360° range. Thus, this implementation must have computation time of the SSB transmission cycle × antenna switching 64 times. In order to display the signal arrival states in a user friendly way on the HMD, data are displayed integrated with 4K video, including the angular profile with a color scheme according to reception level, the cell ID*27 indicating which base station the signal is from, and the peak position from the angular profile, which shows the arrival direction. When there are multiple base stations, measurements can be made for each base station, whether they are using the same frequency or not, and they are displayed with the cell ID for each base station.

Specialized control software makes it possible to perform channel sounding and to check the results

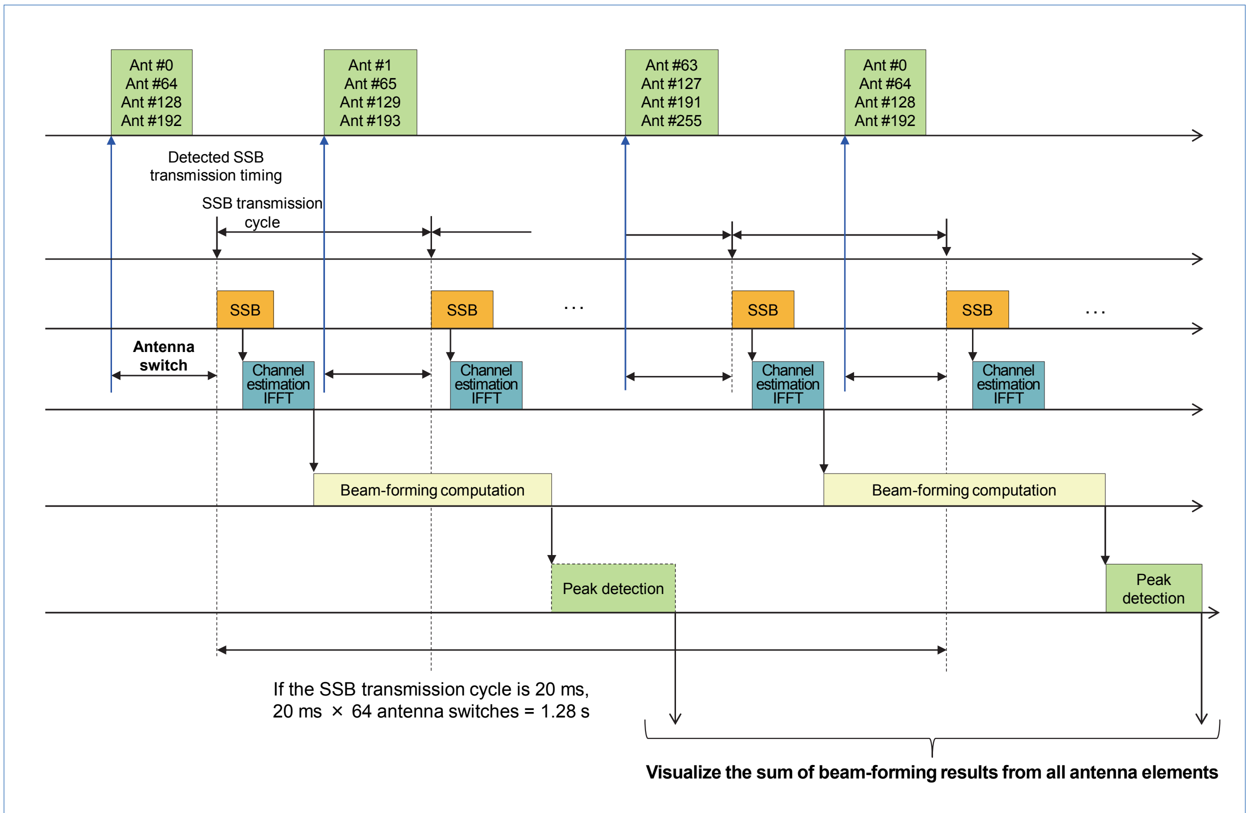


Figure 7 Timing chart for channel estimation, beam forming, and peak detection

*27 Cell ID: An identifier for the base station.

of the analysis easily with this equipment. Channel sounding is performed by just selecting the sub-carrier interval and SSB transmission cycle and pressing the "Start Sounding" button. Intermediate data can be displayed including reception levels and the delay and angular profiles for each antenna element, as shown on the software control screen shot in **Figure 8**.

5. Visualizer Observations

Results of radio observations made using the equipment are shown in **Figure 9**. Fig. 9 (a) shows observation of signal arrival state made with two base stations operating at different frequencies within a radio anechoic chamber. Base station #0, with cell ID of 1, operated at 27.9 GHz, and base station #1 with cell ID of 2, operated at 28 GHz. In the image, color indicates the signal arrival distribution, with red indicating higher reception level, and blue indicating lower reception level. Peaks in the angular profile are shown as dots, and the number displayed above each dot is the cell ID. The image shows that peaks appear near the transmitters for each base station, indicating the signals arriving directly from the base stations. Fig. 9 (b) is the result when operating using the same frequency (27.9 GHz). Compared with Fig. 9 (a), there is more interference between the base stations, which appears as in an overall increase in reception levels. Fig. 9 (c) shows indoor observation of multipath signals*28. Signals arriving directly from the base station and also reflections from walls and other objects are apparent. This shows that the equipment can be used to visualize the effects of structures surrounding the equipment on the state of signals arriving from base stations in real time.

6. Conclusion

This article has described the system architecture and an implementation of a real-time 3GPP radio wave visualizer. The equipment provides a

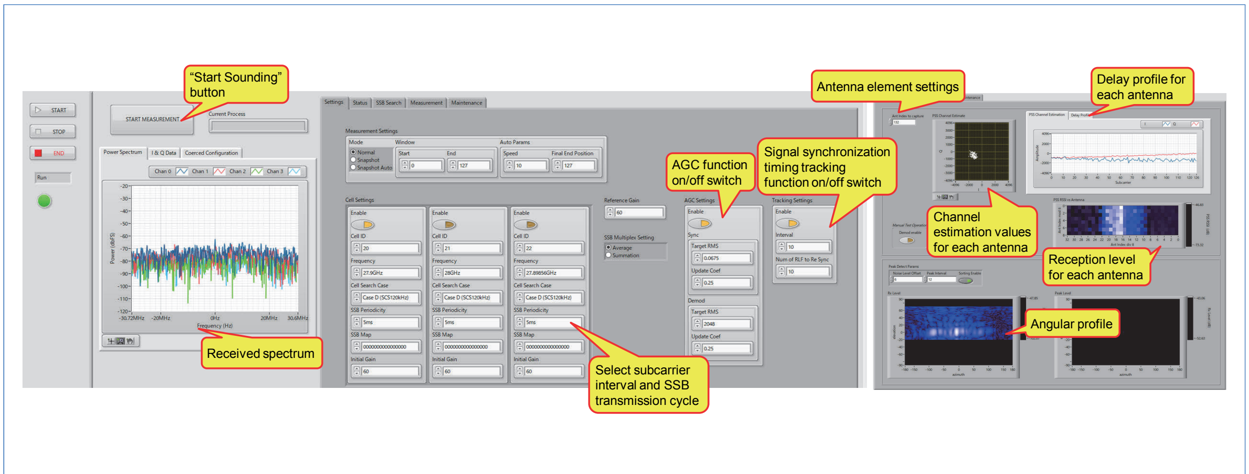
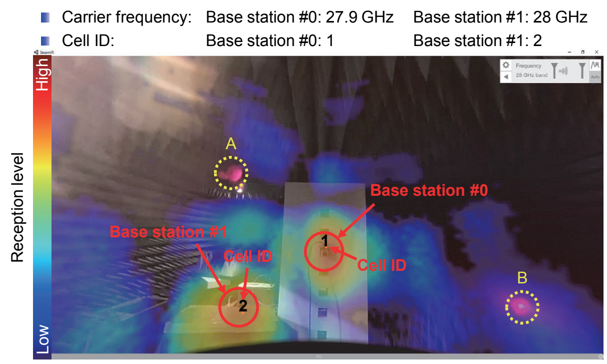
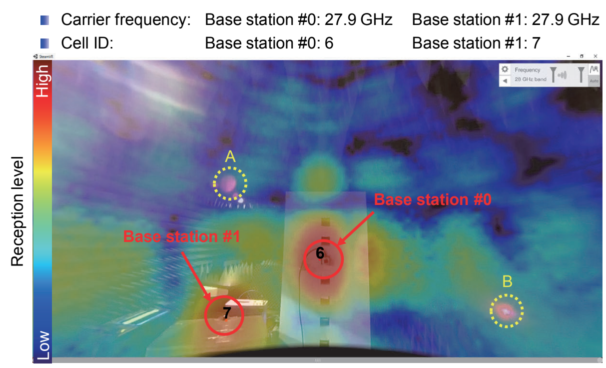


Figure 8 Screenshot of channel sounding control software

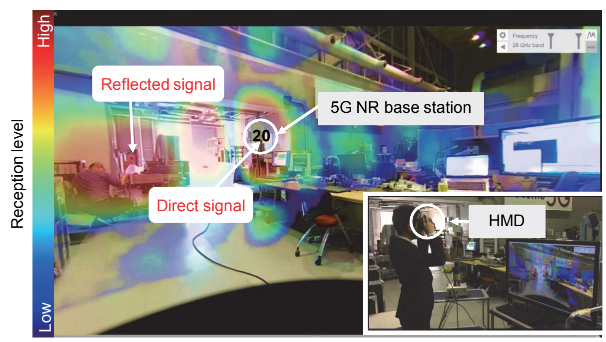
*28 Multipath signal: A signal that reaches the receiving station after traversing various propagation paths.



(a) Observations from base stations using different frequencies in an anechoic chamber



(b) Observations from base stations using the same frequency in an anechoic chamber



(c) Observations in the lab

Figure 9 Observations results

visualization of signal arrival state and can contribute to area optimization for NR-conforming base stations by using it to tune base station parameters such as antenna directionality. We intend to continue to contribute to development of 5G in the future by developing a smaller, general purpose device and promoting its use in various organizations and enterprises.

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