The Missing Piece of Spectrum Autonomy: Taiwan's AFC Implementation Challenges and Localized Spectrum Governance

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***Abstract* — With the rapid development of global 6G mobile communication technology, the effective utilization of spectrum resources has become a strategic priority for nations worldwide. Among these, the harmonized use mechanism of the 5925-7125 MHz band (formerly C-band), particularly the construction and implementation of Automated Frequency Coordination (AFC) systems, serves not only as a critical technical means to ensure harmonious coexistence between unlicensed devices such as Wi-Fi 6E/7 and existing satellite and microwave link services, but also as a core infrastructure to propel Taiwan's spectrum governance toward automation and intelligence. Based on the research findings from the Ministry of Digital Affairs' commissioned research projects "6G Spectrum Readiness and Application Planning" for fiscal years 2024 and 2025, this study encompasses a Proof of Concept (PoC) for system localization, an evaluation of the feasibility of establishing an AFC testing laboratory, and an assessment of the long-term sustainability of the associated business model. The findings and recommendations presented herein are expected to provide valuable references for the development of future spectrum policies and the modernization of spectrum governance frameworks in the 6G era.**

KeyWords—6GHz, AFC, Proof of Concept, System Optimization, Wi-Fi, OPEN AFC, Taiwan.

I. INTRODUCTION (*HEADING 1*)

The rapid rise of Wi-Fi 6E and Wi-Fi 7 technologies has brought revolutionary transformations to the global wireless communications industry. With the commercial deployment of these two next-generation Wi-Fi standards, the effective utilization of the 5925 – 7125 MHz band has become a core issue for spectrum regulators and industrial strategists worldwide. Compared to the conventional 2.4 GHz and 5 GHz bands, the 6 GHz band offers up to 1200 MHz of contiguous bandwidth [1], capable of supporting higher data transmission rates, lower latency, and superior anti-interference capabilities. This possesses irreplaceable strategic value for satisfying the demands of diverse future application scenarios, including ultra-high-definition video streaming, virtual reality (VR), augmented reality (AR), cloud gaming, and the Internet of Things (IoT).

However, the 6 GHz band is by no means empty. Various incumbent services have long existed in this band, including the Radio Astronomy Service, Earth Exploration Satellite Service, Fixed Satellite Service (FSS), and various point-to-point microwave backbone networks [2]. These incumbent services constitute a critical backbone for Taiwan's broadband communication infrastructure, carrying essential tasks such as mass telecommunication backbone transmissions, broadcasting program deliveries, and emergency disaster response communications. Consequently, effectively protecting the legitimate rights of incumbent users and preventing interference conflicts between new and existing services while opening the 6 GHz band for unlicensed Wi-Fi use has become a major challenge that spectrum management authorities in all countries must address.

The emergence of the Automated Frequency Coordination (AFC) mechanism provides a solution that balances both efficiency and fairness for the aforementioned challenges. Distinct from traditional static spectrum allocation methods, AFC adopts a dynamic database-driven mechanism. By establishing a comprehensive database of incumbent stations and employing precise propagation models to calculate the available frequencies and maximum permissible transmit powers for incoming Wi-Fi devices, AFC achieves intelligent and real-time management of spectrum resources. This mechanism not only effectively safeguards the communication quality of incumbent users but also maximizes the utilization efficiency of the 6 GHz band, promoting the optimized configuration of spectrum resources [3].

In recent years, Taiwan has taken an active and pragmatic approach to the construction of AFC systems. It has successfully completed the localized optimization of the TIP Open AFC open-source software, established an incumbent station database, joined the WinnForum organization, and maintained continuous engagement with international networks. Nevertheless, during the field implementation of the system, Taiwan still faces multiple challenges, including database integrity maintenance, propagation model validation, the establishment of equipment verification frameworks, and the sustainability of business models [4][5]. The existence of these challenges affects not only the effective operation of the AFC system but also the modernization level of Taiwan's spectrum governance capabilities in the upcoming 6G era.

This study aims to systematically investigate the implementation challenges and localized spectrum governance strategies for Taiwan's AFC system. Based on in-depth analyses and research outcomes from 2024 (the 113th year of the Republic of China) and 2025 (the 114th year), this paper will elucidate the fundamental principles and developmental trends of AFC systems, evaluate the achievements of Taiwan's localized autonomous optimization of the AFC system, analyze the progress and findings in testing and verification, and accordingly propose policy recommendations for Taiwan's localized AFC governance. The findings and recommendations of this study can serve not only as a reference for Taiwan's future spectrum policymaking but also as a benchmark for other countries currently promoting the construction of AFC systems.

II. AFC ARCHITECTURE

The AFC system adopted in this study is Open AFC, which was developed by the Open AFC Software Group under the Telecom Infra Project. The group provides a cloud-based collaborative platform that enables developers worldwide to participate in software development and enhancement, thereby promoting the growth of unlicensed services in the 6 GHz band.

Open AFC is a modular software system that allows AFC operators to extend and customize its functionality to meet diverse market requirements. At present, Open AFC has been adopted by multiple AFC system operators as the foundation for their AFC solutions.

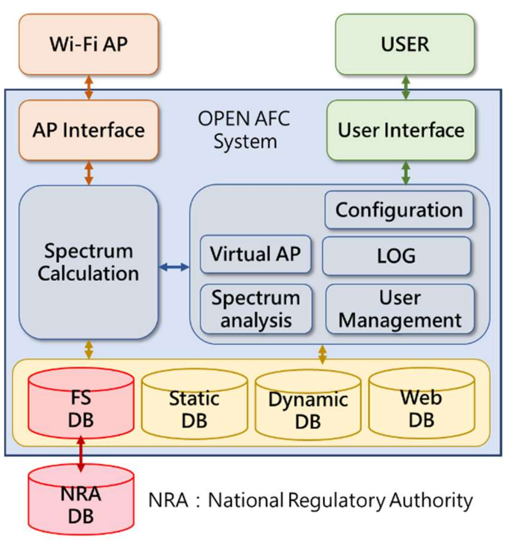

Fig. 1. OPEN AFC Architecture

The Open AFC system architecture is illustrated in Fig. 1, which is fundamentally structured into three core categories: the AFC System Interfaces, the AFC Functional Modules, and the Database layer. The detailed descriptions of these components are elaborated below:

A. AFC System Interfaces

- Physical AP Spectrum Request Interface: This interface allows registered Access Points (APs) to submit spectrum allocation requests to the AFC system. After the spectrum calculation is completed, the AFC system returns the available frequency channels to the AP. The functions associated with this interface are represented in orange.
- Registered User Interface: Registered users can access and operate AFC system functions through a web-based interface. The functions associated with this interface are represented in green.
- Fixed Service Database Interface: Through this interface, the AFC system updates Fixed Service station information on a daily basis from databases provided by the regulatory authority. Since the methods and formats used by regulators vary across countries, this interface must be customized accordingly.

B. AFC Functional Modules

- Spectrum Calculation Module： This is the core calculation engine of the AFC system, providing functions such as spectrum assignment and spectrum analysis. Calculations are performed using the selected radio propagation models. Both physical AP operations and user analysis functions rely on this module.
- System Functions Module ： Provides various functions that users can access and operate through the web interface.。
- User Management Module: Manages registered users and authorized APs within the AFC system.。
- Parameter Management Module: Allows administrators to configure parameters used by the spectrum calculation engine and select database options.
- Virtual AP Module: Simulates a physical AP submitting a spectrum request at a specified location and displays the resulting AFC response through the web interface for user reference and analysis.
- Spectrum Analysis Module: The system provides a user interface equipped with functions for fixed-point analysis, heatmap analysis, and exclusion zone analysis.
- Request Logging Modul: Storage of Authorized AP AFC Request Messages, AFC Response Message, AFC Engine Log, AFC Config Record and Map Data.

C. Databases

- Fixed Service Database (Red): Stores Fixed Service station information that is updated daily. This database must be integrated with databases provided by regulatory authorities, requiring customized software development to accommodate different data formats and access mechanisms.

- Static Database: This category hosts databases with an update cycle exceeding one year, which primarily include geographic information system (GIS) databases, building layout databases, and propagation path model datasets. Although the Fixed Service station database requires daily updates, it is treated as a special exception and classified under this category due to its architectural relevance.
- Dynamic Database: This category accommodates databases that require frequent updates or real-time data ingestion within short intervals. It primarily encompasses the antenna pattern database, user/subscriber profiles, and spectrum inquiry log databases.
- Web Data：Web-Related Data Storage。

III. Localized Optimization of Taiwan's AFC System

Since Open AFC was initially designed for the operating environments of the United States and Canada, it cannot be directly deployed in other regions. Consequently, modifications to Open AFC are required to adapt it to the environment in Taiwan[7]. This is followed by the incorporation of Taiwan-specific data—including incumbent stations, Wi-Fi devices, terrain elevation, and land cover types—into the Open AFC database. Furthermore, to maintain compliance with the AFC system reference model proposed by the Wi-Fi Alliance [8], it is necessary to additionally construct a ULS database and integrate type approval data for Wi-Fi access points (APs).

A. *Conversion of Taiwan's Geographic Information and Topographic Data*

The AFC system relies on elevation maps to compute the three-dimensional (3D) distances between Wi-Fi devices and Fixed Service stations. These elevation maps are also utilized to determine whether topographic obstacles obstruct the wireless radio links between the devices and Fixed Services. Therefore, the resolution and granularity of the elevation data significantly impact the selection and accuracy of the radio propagation path loss models.

The cartographic and geographic functionalities within Open AFC are inherently tailored to U.S. standards; its native terrain and land cover data do not support deployment in non-North American regions. Although Open AFC includes a built-in global elevation dataset as a fallback, its low resolution inevitably introduces calculation errors across far, medium, and near distances (exceeding 1 km, between 30 m and 1 km, and within 30 m, respectively). This represents one of the primary challenges when deploying Open AFC in Taiwan. Additionally, the lack of localized land cover data for Taiwan results in discrepancies between simulated clutter loss calculations and actual environmental characteristics.

To achieve geographic optimization, this study analyzes the conversion methodologies of the U.S. 3D Elevation Program (3DEP) and National Land Cover Database (NLCD) [9] native to Open AFC. Through this process, Taiwan's geographic data with a 20-meter resolution is successfully converted and imported into the Open AFC database, enabling the system to properly read Taiwan's terrain data and execute related calculation functions.

B. *Establishment of Taiwan's Fixed Service Station Database*

Since the regulatory agency in Taiwan does not publicly disclose Fixed Service station data operating in the 6 GHz band, this study not only obtained Fixed Service service station data within the 5945–7125 MHz frequency range from the authority, but also established a Taiwan-specific ULS database compliant with the OPEN AFC specifications. The overall architecture of the proposed database is illustrated in Fig. 2. The database supports functionalities including role-based access control according to user categories, editing and querying Fixed Service station data, importing and exporting data in CSV format, converting data into AFC system-specific formats, and providing application programming interfaces (APIs) for AFC system access.

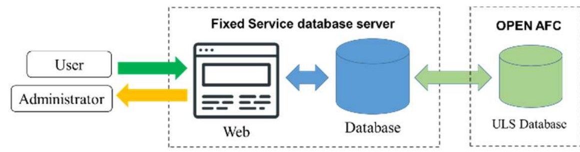

Fig. 2. Fixed Service Database Architecture.

After comparing the Fixed Service station data fields defined by the regulatory agency with those specified in OPEN AFC, it was found that the regulatory data lacked several key parameters, including antenna model, antenna gain, polarization, and near-field parameters. Therefore, this study also requested relevant information from Fixed Service station operators to enhance the completeness of the Fixed Service station database and improve the accuracy of interference calculations.

Finally, the Virtual AP functionality within Open AFC was utilized to verify the system implementation. The verification confirmed that the localized Fixed Service station information was successfully imported into the Open AFC ULS database, as illustrated in Fig. 3. To date, a total of 679 microwave transmission links encompassing television, radio broadcasting, telecommunications, power utilities, and the Ministry of Economic Affairs (MOEA) have been successfully integrated into the Open AFC system.

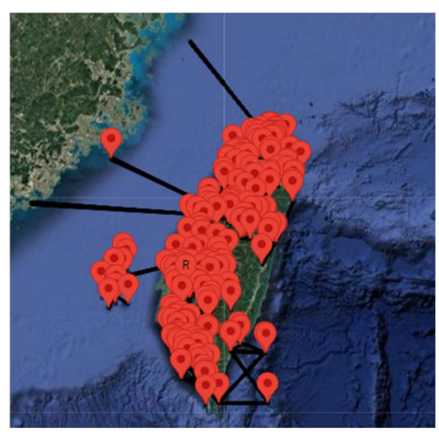

Fig. 3. Geographical distribution of Fixed Service stations in Taiwan.

C. *Acquisition of Taiwan's NCC Type Approval Data*

While the FCC provides dedicated APIs for credential databases that Open AFC can seamlessly access, Taiwan's NCC type approval database lacks an external API for thirdparty integration. Instead, the NCC traditionally publishes these regulatory records as downloadable files (such as XLS and CSV formats) on its web portal. To bridge this technical gap, this study developed a Python-based interface capable of performing scheduled web scraping to download type approval datasets from the NCC portal. The program filters equipment based on specified certificate serial numbers and automatically injects the parsed data into the Open AFC database, as illustrated in the workflow in Fig. 4.

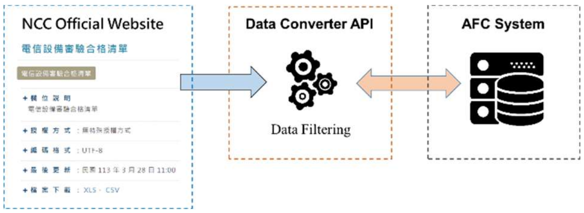

Fig. 4. Workflow of importing NCC data into the AFC system.

The publicly accessible NCC type approval database contains over 96,000 historical records spanning from 1991 to the present, encompassing all certified radio frequency (RF) equipment, including Wi-Fi 6E and Wi-Fi 7 devices. Since Taiwan has not yet officially permitted the commercial operation of standard-power Wi-Fi devices, the future implementation of the AFC mechanism will inevitably require expanding the equipment classification framework. Specifically, a dedicated category for "6 GHz standard-power equipment" must be introduced into the NCC type approval registry. This adaptation is crucial to distinctively differentiate standard-power devices from existing low-power indoor (LPI) or very low-power (VLP) equipment.

IV. Testing and Verification of Taiwan's AFC System

To evaluate the feasibility and applicability of introducing AFC mechanisms in Taiwan, this study conducted field measurements and validation of interference scenarios between AFC-enabled devices and incumbent Fixed Service (FS) microwave links. By performing interference analysis and frequency coordination through AFC devices, the study examined whether the calculation results generated by the AFC core algorithms are suitable for Taiwan's geographical environment, existing system deployment characteristics, and spectrum utilization scenarios.

In addition, by referencing the technical requirements and validation procedures established by the Federal Communications Commission (FCC), AFC devices were subjected to measurement and functional verification tests to assess whether Taiwan's existing testing capabilities and certification mechanisms are sufficient to support AFC equipment testing and certification.

The results of this study may serve as a technical reference for the future implementation of AFC regulations and validation mechanisms in Taiwan. Furthermore, the findings provide recommendations for 6 GHz spectrum management and coexistence policies, helping to reduce interference risks to incumbent users, improve spectrum utilization efficiency, protect consumer interests, and support the long-term development of Taiwan's information and communications technology industry.

A. *AFC System Optimization and Field Validation*

According to the operational mechanism of the Automated Frequency Coordination (AFC) system, frequency assignment parameters are primarily determined based on the deployment environment of the interfering device, the separation distance from incumbent Fixed Service (FS) stations, and whether a Line-of-Sight (LoS) path exists between the stations.

Accordingly, the test environments were classified into three representative categories: Urban, Suburban, and Rural. Distance conditions were further divided into three ranges: within 30 meters, between 30 and 1,000 meters, and greater than 1,000 meters from the incumbent microwave station. Each distance category was further separated into Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) conditions, resulting in multiple representative test scenarios, as illustrated in Fig. 5.

Fig. 5. Example of Test Range Intervals

In addition to utilizing a commercial Wi-Fi AP to verify the practical operation of the AFC system, a signal generator was employed to emulate worst-case interference conditions in order to evaluate the interference protection capability provided by the AFC system.

Field interference validation was conducted at three representative locations: Xincuo (Urban Environment), Donggang (Suburban Environment), and Hsing Tung Building (Rural Environment). During testing, the AFC system calculated and provided transmission parameters according to the environmental category, separation distance, and visibility conditions of each test point. These parameters were then configured into the interference device, which transmitted signals toward the incumbent microwave link.

Meanwhile, the operator's backend monitoring system continuously observed received signal quality and link performance to determine whether any perceivable interference occurred. The overall testing procedure is shown in Fig. 6.

The measurement results demonstrated that no significant interference was observed on the incumbent FS links when transmissions were conducted using AFC-authorized parameters under urban, suburban, and rural environments. These results indicate that the AFC system provides effective interference mitigation through its power control and frequency coordination mechanisms.

To further verify the Interference Protection Margin reserved by the AFC system, an additional Power Margin Verification test was conducted at the Donggang test site. A signal generator combined with a directional antenna was used to gradually increase transmission power until interference thresholds were observed on the incumbent link.

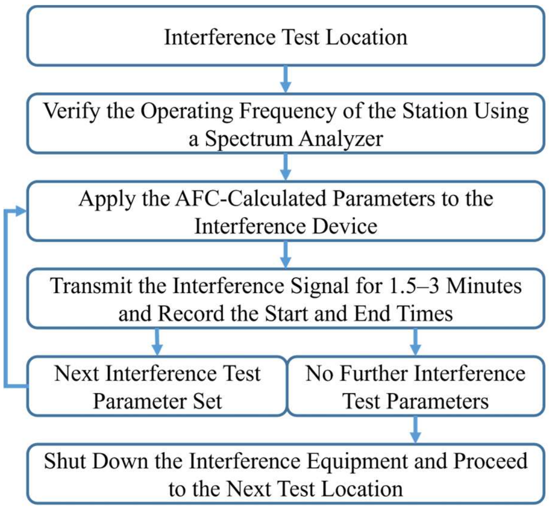

Fig. 6. Interference Testing Workflow

The results showed that noticeable interference was observed only at test points located between 30 and 1,000 meters under LoS conditions, as illustrated in Fig. 7.

Further analysis revealed that the actual transmission power required to generate interference was approximately 10 dB higher than the maximum power authorized by the AFC system. This result indicates that the AFC system maintains an adequate protection margin under the evaluated scenario and can effectively reduce the risk of harmful interference to incumbent FS links.

Existing Site Receiver Frequency: 6286.19 MHz

Donggang LoS Area

P2 (LoS)	Frequency (MHz)	Tx Power (dBm)	Height Above Ground (m)	Bandwidth (MHz)	Interference (Yes / No)	Distance Range to Site (m)	AFC System Zone
1	6295	16.8	2	20	No	30~1000	Yellow Zone
2	6295	18	2	20	No	30~1000	Yellow Zone
3	6295	21	2	20	No	30~1000	Yellow Zone
4	6295	24	2	20	No	30~1000	Yellow Zone
5	6295	27	2	20	No	30~1000	Yellow Zone
6	6295	30	2	20	Yes	30~1000	Yellow Zone
7	6295	33	2	20	Yes	30~1000	Yellow Zone
8	6295	36	2	20	Yes	30~1000	Yellow Zone
9	6315	36	2	20	No	30~1000	Green Zone
10	6285	19.8	2	40	No	30~1000	Yellow Zone
11	6285	21	2	40	No	30~1000	Yellow Zone
12	6285	24	2	40	No	30~1000	Yellow Zone
13	6285	27	2	40	No	30~1000	Yellow Zone
14	6285	30	2	40	Yes	30~1000	Yellow Zone
15	6285	33	2	40	Yes	30~1000	Yellow Zone
16	6285	36	2	40	Yes	30~1000	Yellow Zone
17	6325	36	2	40	No	30~1000	Green Zone
18	6305	22.8	2	80	No	30~1000	Yellow Zone
19	6305	24	2	80	No	30~1000	Yellow Zone
20	6305	27	2	80	No	30~1000	Yellow Zone
21	6305	30	2	80	No	30~1000	Yellow Zone
22	6305	33	2	80	Yes	30~1000	Yellow Zone
23	6305	36	2	80	Yes	30~1000	Yellow Zone
24	6345	25.9	2	160	No	30~1000	Yellow Zone
25	6345	27	2	160	No	30~1000	Yellow Zone
26	6345	30	2	160	No	30~1000	Yellow Zone
27	6345	33	2	160	No	30~1000	Yellow Zone
28	6345	36	2	160	Yes	30~1000	Yellow Zone

Fig. 7. Donggang Proximity Interference Test Results

B. *Identify the Headings*

At present, AFC systems and associated equipment have not yet been authorized for operational deployment in Taiwan. Therefore, prior to future implementation, it is necessary to assess whether sufficient domestic testing and validation capabilities exist.

To address this objective, this study conducted testing and verification of a Standard-Power AFC Wi-Fi AP in accordance with the requirements specified in FCC 47 CFR Part 15[10], producing a complete AFC equipment test report.

A comprehensive AFC equipment verification report should include the following components:

- RF Measurement Testing
- AFC Device Under Test (DUT) Verification
- Geolocation Consistency Verification

The overall AFC testing framework is shown in Fig. 8.

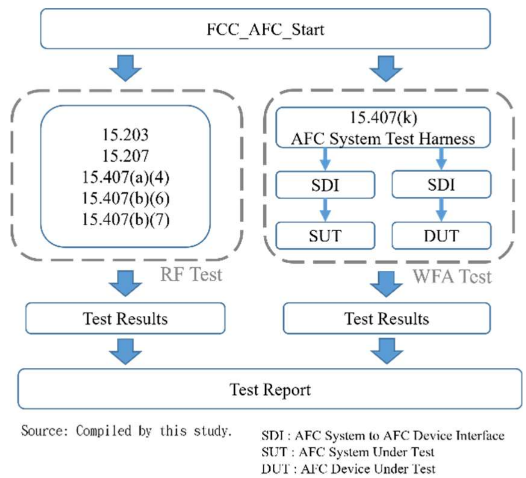

Fig. 8. Complete AFC Device Test Architecture

RF testing was performed according to FCC requirements specified in Sections 15.203, 15.207, 15.407(a)(4), 15.407(b)(6), and 15.407(b)(7). The RF evaluation consisted of three primary categories:

- Power Line Conducted Emissions Testing
- Antenna Port Testing
- Radiated Emissions Testing

The RF test architecture is illustrated in Fig. 9.The AFC DUT verification was conducted using the Test Harness tool and followed the requirements specified in FCC Section 15.407(k).

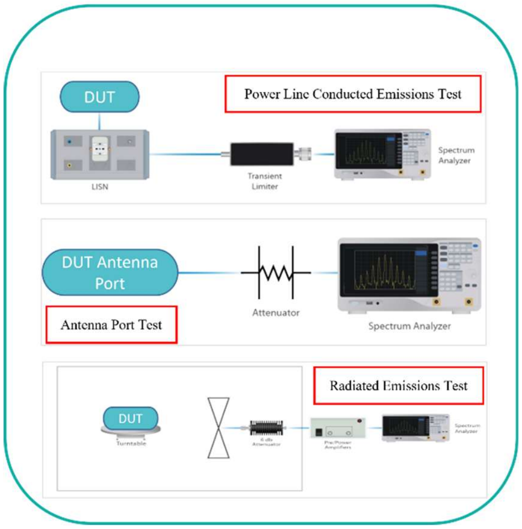

Fig. 9. RF Test Architecture Diagram

Currently, no FCC-recognized laboratory in the United States performs dedicated geolocation consistency verification for AFC devices. Therefore, this study established a geolocation verification methodology based on satellite positioning systems. The corresponding testing process and architecture are shown in Fig. 10.

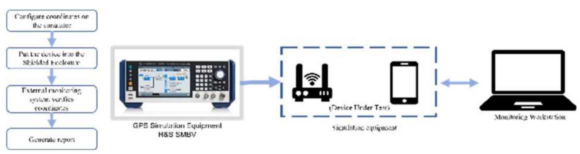

Fig. 10. RF Test Architecture Diagram

Two primary geolocation implementation methods are currently adopted by Standard-Power Wi-Fi AP manufacturers. The first method utilizes an integrated GPS module within the AP itself, making the AP the test subject. The second method obtains location information through a mobile application, with the smartphone serving as the test subject. This study adopted the second approach.

The shielding enclosure and associated test equipment used during measurements are shown in Fig. 11.

Fig. 11. Test Equipment Diagram

Location and altitude information were collected through a mobile application, resulting in 14,524 location samples. The measured horizontal mean error was 134.41 cm, with a standard deviation of 150.49 cm. Using a 95% confidence level, the calculated confidence interval was 131.96 cm to 136.86 cm, corresponding to a horizontal positioning accuracy of approximately 1.32–1.37 meters.

For the vertical dimension, the mean error was −3.13 cm, with a standard deviation of 3.60 cm. The corresponding 95% confidence interval ranged from −3.19 cm to −3.07 cm, resulting in a vertical accuracy of approximately 0.031–0.032 meters.

When compared with the accuracy requirements specified in the Global Positioning System Standard Positioning Service (SPS) Performance Standard, shown in Fig. 12, both the measured horizontal and vertical positioning accuracies demonstrated excellent performance.

Position/Time Accuracy Standard	Conditions and Constraints
Global Average Position Accuracy ● ≤ 8 m 95% Horizontal Error ● ≤ 13 m 95% Vertical Error	● Defined for a position/time solution meeting the representative user conditions ● Position/time solution is available
Worst Site Position Accuracy ● ≤ 15 m 95% Horizontal Error ● ≤ 33 m 95% Vertical Error	● Defined for a position/time solution meeting the representative user conditions ● Position/time solution is available
Global Average Velocity Accuracy ● ≤ 0.2 m/sec 95% velocity error, any axis	● Defined for a position/velocity/time solution meeting the representative user conditions ● Position/velocity/time solution is available
Time Transfer Accuracy ● ≤ 30 ns Time Transfer error 95% of time (SIS only)	● Defined for a time transfer solution meeting the representative user conditions ● Time transfer solution is available

Fig. 12. SPS Position/Velocity/Time Accuracy Standards

During the course of testing, a detailed review of existing regulations and measurement methodologies was also conducted. The study found that the current FCC geolocation verification mechanism still contains certain limitations. Specifically, the AFC system cannot reliably determine whether an AP has been physically relocated after registration, which may introduce uncertainty into interference assessments.

Future work should focus on strengthening geolocation verification mechanisms to improve the overall reliability and practical effectiveness of AFC interference management and spectrum coordination.

V. Conclusions

This study references the specifications released by international organizations such as the FCC, Wi-Fi Alliance, and Telecom Infra Project (TIP) to establish an AFC operational environment tailored for Taiwan. Key milestones achieved include the optimization of Taiwan's topographic and land cover data, the development of a localized ULS database, the integration of the NCC type approval registry, and physical AP testing. Notably, the localized ULS database and the integration interface for the NCC type approval registry constitute indispensable elements for future commercial AFC operators deploying systems in Taiwan.

A. Immediate and Actionable Recommendations

- Establishment of Regional Spectrum Protection Zones: Considering that Taiwan's highly dense and urbanized environment differs fundamentally from that of the United States, it is recommended to initially establish regional spectrum protection zones if the AFC system is to be deployed immediately. This measure will safeguard the frequency bands utilized by incumbent stations across various regions from immediate interference, thereby maintaining the stability of existing wireless communication services.
- Private-Sector Participation in AFC Operations: Regarding the operational model of the AFC system,

Taiwan could adopt the U.S. approach by permitting technically capable private enterprises to participate in management and operations. However, the system design and operational management workflows of these entities must undergo rigorous review and certification by the central regulatory authority to ensure operational security and regulatory compliance.

B. *Medium- to Long-Term Recommendations*

- Localization of Land Cover Classifications and Clutter Models: To achieve efficient spectrum sharing and maximize utilization through the AFC system, several dimensions within Taiwan's operational environment still require substantial improvement. Currently, land cover data and clutter models inherit methodologies from the United States. Given the significant geographical differences between Taiwan and the U.S., it is recommended to redefine land cover classifications and clutter models that reflect Taiwan's localized characteristics, thereby enhancing the precision of interference predictions.
- Construction of a Dedicated 3D Building Dataset: In terms of structural topography, Taiwan currently lacks a comprehensive building dataset. This deficiency leads to a lack of reliable benchmarks when evaluating the shielding effects of terrestrial obstructions (e.g., buildings), which easily introduces deviations into calculation results. To elevate the accuracy and practicality of the AFC system, Taiwan should construct a dedicated building database to reinforce its spatial information infrastructure.
- Mitigation of Aggregate Interference in High-Density Environments: Given Taiwan's high population and structural density, the deployment of standard-power access points (APs) introduces a high probability of signal energy overlapping from multiple devices, thereby escalating the risk of aggregate interference. Consequently, it is imperative to conduct extensive simulations and field trials to evaluate these potential impacts and formulate corresponding mitigation strategies. These insights will further optimize AFC system algorithms to achieve the global maximization of spectrum efficiency.

C. *Future Extended Applications and 6G Evolution*

With the imminent arrival of sixth-generation (6G) mobile communications, the release of new International Mobile Telecommunications (IMT) spectrum is an inevitable trend. However, as pristine, unoccupied spectrum becomes increasingly scarce, the importance of spectrum sharing mechanisms grows exponentially. The methodologies and database architectures proposed in this study will provide substantial contributions to the development and model training of future intelligent spectrum management systems.

Furthermore, leveraging the research experience gained from the AFC system allows the extension of unlicensed spectrum sharing concepts into the licensed spectrum domain. This facilitates the investigation of interference risks posed by mobile cellular base stations to incumbent stations, ensuring the stable operation of the surrounding wireless ecosystem. This dual approach not only enhances spectrum utility but also addresses the critical challenge of clean spectrum scarcity. The technical expertise accumulated in AFC technologies through this study establishes a robust foundation for the introduction of intelligent spectrum management. Through the integrated application of these achievements, future spectrum governance will evolve toward a smarter, more flexible paradigm, ultimately realizing a highly efficient, user-centric spectrum resource allocation mechanism.

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However, owing to limitations in the research timeline, resource allocation, and overall scope, certain omissions and deficiencies may inevitably remain within this work. The authors warmly welcome constructive feedback, critiques, and insights from fellow researchers, industry experts, and scholars to serve as a valuable reference for continuous refinement and further exploration in future studies.

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