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블록체인과 스마트 계약을 활용한 효율적인 5G 세라믹 안테나 제조 아키텍처

Efficient 5G Ceramic Antenna Manufacturing Architecture using Blockchain and Smart Contracts

안 성 용[1] · Guy Ngayo[2] · 홍 승 필[3*]
[1]서울종합과학대학원대학교 경영대학원 & 스위스 프랭클린대학교 경영대학원
[2]스위스 프랭클린대학교 경영대학원
[3*]서울종합과학대학원대학교 AI전문대학원

Sung Yong An[1] · Guy Ngayo[2]· Seng-Phil Hong[3*]
[1]Student, Seoul Business School, aSSIST University, Seoul 03767, Korea / Franklin University Switzerland
[2]Professor, School of Business, Franklin University Switzerland, Sorengo 6924, Switzerland
[3*]Professor, School of AI, aSSIST University, Seoul 03767, Korea

[요 약]

이 연구는 블록체인 기반 5G 세라믹 안테나 제조(B-5GAM) 아키텍처를 활용하여 5G 세라믹 안테나 제조 공정의 복잡성을 해결하기 위한 새로운 접근 방식을 소개한다. 이 아키텍처는 블록체인 기술과 스마트 컨트랙트를 원활하게 통합하여 5G 세라믹 안테나 제조 영역에서 투명성, 보안성, 효율성을 향상시켰다. 블록체인을 적용하여 보안 조치, 프로세스 효율성 및 전반적인 신뢰성을 향상시킴으로써 생산 프로세스를 최적화할 뿐만 아니라 향후 통신 기술 발전을 위한 견고한 기반을 구축하는 효과는 분명하다. 5G 안테나를 제조하고 블록체인 및 스마트컨트랙트를 적용하기 위한 알고리즘 제시를 통해 B-5GAM 아키텍처를 검증하고 실제 제조 환경에서의 적용 가능성을 확인하였다. 이 연구 결과는 5G 세라믹 안테나 제조 분야에서 블록체인과 스마트 컨트랙트의 활용 가능성을 입증하여 제조 효율성과 신뢰성을 향상시킬 수 있음을 확인하였다.

[Abstract]

This research introduces a novel approach to address the complexities of the 5G ceramic antenna manufacturing process through the utilization of a blockchain-based 5G ceramic antenna manufacturing (B-5GAM) architecture. By seamlessly integrating blockchain technology and smart contracts, this architecture enhances transparency, security, and efficiency within the realm of 5G ceramic antenna manufacturing. The impact of applying blockchain to enhance security measures, process efficiency, and overall reliability is evident, not only optimizing the production process but also establishing a robust foundation for future advancements in communication technology. Validation of the B-5GAM architecture was achieved by manufacturing 5G antennas and implementing blockchain and smart contracts through algorithm proposals, confirming their practicality in real manufacturing environments. The results of this study demonstrate the feasibility of employing blockchain and smart contracts in the field of 5G ceramic antenna manufacturing, confirming their potential to enhance manufacturing efficiency and reliability.

Key word : Blockchain, 5G Antenna Manufacturing, Smart contract, 5G Communication, Efficiency.

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***Corresponding Author: Seng-phil Hong**

Tel: +82-2-70-7012-2700
E-mail: sphong@assist.ac.kr

Ⅰ. Introduction

5G communications are increasingly assuming a crucial role in contemporary society, giving rise to groundbreaking services and products leveraging 5G technology across diverse industries. In the domain of 5G ceramic antenna manufacturing, there are significant expectations concerning security, adherence to standards and regulations, and operational efficiency, as these aspects hold the potential to influence multiple sectors within modern industry. Blockchain stands out as a pivotal technology driving the 4th industrial revolution, finding heightened adoption in manufacturing and supply chain management due to its exceptional reliability and robust security [1]-[7].

For corporations with manufacturing facilities both domestically and internationally, meticulous attention is required in logistics and security during inter-facility transfers. The potential consequences of information leaks have led to the widespread adoption of blockchain technology in logistics and supply chain domains, due to its elevated levels of security, transparency, and data integrity. Additionally, blockchain technology has expanded its utility by integrating smart contracts, which can autonomously execute contractual conditions [8]-[11].

This study aims to enhance the defect management and manufacturing process in the domain of 5G ceramic antenna manufacturing, primarily through the adoption of blockchain technology and smart contracts. The 5G communication protocol embraces the 24-43 GHz frequency band as opposed to the conventional 2.1 GHz band [12], while the 5G ceramic antenna manufacturing process encompasses approximately 12 distinct stages. Any occurrence of a defect or malfunction within a single stage necessitates a complete process restart, incurring significant time and financial costs. To address this issue, blockchain technology is employed to meticulously record problems encountered at each stage, and smart contracts facilitate the automatic progression of the process to subsequent stages. This proactive approach enables swift problem detection and resolution, ultimately leading to time and cost savings.

Security, standards compliance, and efficiency in manufacturing 5G ceramic antennas are significant topics that affect the entire industry. Therefore, antenna manufacturers must uphold high standards to meet customer demands, gain trust from stakeholders, and remain competitive. This study leverages blockchain technology to assess the benefits of security, compliance, and efficiency. Blockchain offers decentralization, immutability, and transparency, making it invaluable for enhancing security and data integrity. Adherence to standards and regulations ensures product quality and market confidence. Efficiency in manufacturing is vital for competitiveness and success.

In this paper, we propose the B-5GAM architecture, which effectively addresses process issues and enhances productivity by utilizing blockchain technology and smart contracts in 5G ceramic antenna manufacturing. We delve into the theoretical foundations of 5G communication, blockchain, and smart contracts, analyze challenges specific to 5G ceramic antenna manufacturing, and introduce a methodology combining blockchain and smart contracts to enhance transparency and security. The B-5GAM architecture provides a holistic solution to boost transparency and efficiency in 5G ceramic antenna production, resolving supply chain complexities, production process ambiguities, technical hurdles, and workforce-related challenges while reducing defect rates. The incorporation of blockchain and smart contracts fosters improved trustworthiness between manufacturers and customers, thereby guaranteeing the quality and safety of the final products. By conducting an extensive analysis, we evaluate the advantages and limitations of applying blockchain and smart contracts in 5G ceramic antenna manufacturing, while also presenting potential areas for future research and enhancement.

Ⅱ. Theoretical background

2-1 5G Communication

5G communication refers to the 5th generation of mobile communication technology, which offers higher data rates and the ability to connect more devices simultaneously compared to existing 3G and 4G mobile communication [13]. 5G is characterized by ultra-high data rates, ultra-low latency, and hyper-diversity, enabling advancements in areas such as massive data transmission and the Internet of Things (IoT) [14]-[15]. The speed of 5G far exceeds that of existing mobile communication technologies. It can provide download speeds of up to 20 Gbps per second, approximately 20 times faster than 4G's 1 Gbps and 3G's 384 Kbps. This enables uninterrupted streaming of HD or 4K high-definition videos and supports real-time services like gaming, virtual reality (VR), and augmented reality (AR). Additionally, 5G offers ultra-low latency, reducing delays to sub-milliseconds. As a result, real-time services can achieve high accuracy and stability. Moreover, 5G supports hyper-diversity, allowing thousands of devices to be connected simultaneously. This capability is especially valuable in scenarios like smart cities, autonomous vehicles, and industrial robotics, where large-scale device connectivity is essential. Currently, these 5G technologies are being commercialized worldwide and are anticipated to drive a new industrial revolution by finding applications in an even broader range of fields in the future [16]-[18].

For the advancement of 5G communications, the technology of 5G ceramic antennas must also progress. The role of 5G ceramic antennas is to both receive and transmit radio signals, and they need to support higher bandwidth and faster data rates. Unlike most antennas currently in use that operate in fixed directions, 5G ceramic antennas require greater flexibility to receive and transmit signals in various directions. Consequently, antenna technology capable of fine adjustments is under development, which enables more precise directionality and higher signal strength. Additionally, 5G ceramic antennas must be smaller and lighter. Traditionally, large antennas have been utilized for high performance, but a new approach is needed to transmit and receive data in more diverse directions using multiple antennas. In light of this, ongoing technical research aims to develop smaller antennas [19]-[20].

5G ceramic antennas should enable more efficient and economical energy usage. As 5G communication requires high power to support its high transmission speed and bandwidth, minimizing power consumption is crucial through antenna improvements. Hence, ongoing technical research is being conducted to enhance energy efficiency.

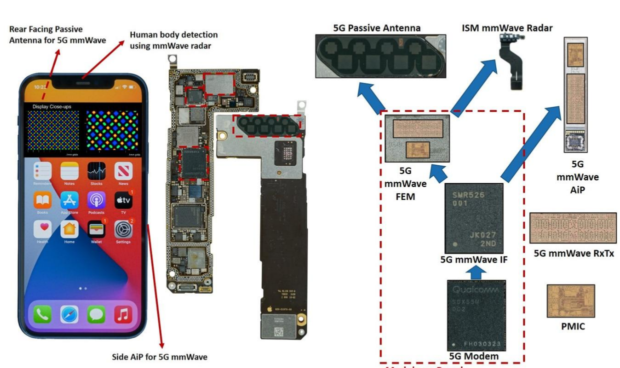

Fig. 1. iPhone 12 RF front end analysis (Source: https://www.eetasia.com/5g-antenna-designs-coping-with-human-blockage/

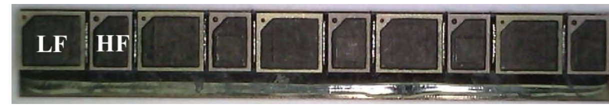

Fig. 2. Photo-image of the fabricated 1 x 5 antenna array using the multi-stacked ceramic antenna on package

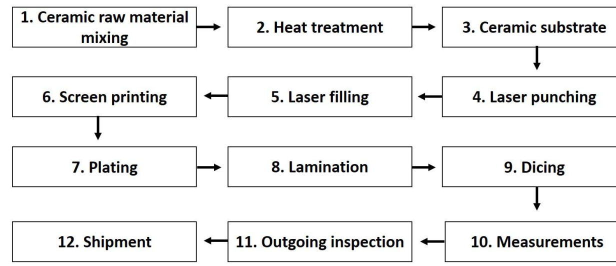

Fig. 3. 5G Ceramic Chip Antenna manufacturing process

For the continued development of 5G communication, the continuous advancement of antenna technology is necessary to support higher bandwidth and faster data rates. Through these improvements, 5G communication can achieve its full potential [21]-[22]. The 5G millimeter wave antenna was integrated into the Apple iPhone 12, initially released in the United States. As depicted in Fig. 1, a teardown analysis was conducted, revealing two types of 5G antennas present in the iPhone 12: those attached to the side and those integrated into the body. The thickness of the iPhone 12 is largely influenced by the side-attached antennas, thus prompting the replacement of existing antennas with 5G ceramic antennas to reduce the phone's overall thickness. Conventional 5G antennas typically employ a PCB (Printed Circuit Board) material with a low permittivity of 3.45. However, this material's limitations in reducing antenna size have led to ongoing research aimed at using ceramics with higher permittivity as alternative materials for manufacturing 5G antennas. The physical length of the antenna is closely related to the effective wavelength of the medium, represented as $\lambda_{eff}/2$, as expressed in Equation(1) [21]-[23].

$$\lambda_{eff} = \frac{\lambda_0}{\sqrt{\mu_r \epsilon_r}}, \tag{1}$$

where λ_0 denotes the wavelength in a vacuum, ε_r represents the relative permittivity, and μ_r signifies the relative magnetic permeability. The physical length of the antenna can be reduced by employing a dielectric material with permittivity ε_r. When comparing ceramics with dielectric constants of 3.5 and 9.45, typical for PCB materials, the physical lengths at 26GHz were measured at 3.1mm and 1.97mm, respectively. Various ceramic materials can be manufactured with dielectric constants ranging from 6 to 30. In this study, the dielectric constant of the 5G ceramic antenna materials 9.45, and Fig.2 illustrates the 5G ceramic chip antenna. To create the 5G ceramic antenna array, LF (LowFrequency) ceramic chips capable of operating in the 26.5GHz~28.35GHz band and HF (HighFrequency) ceramic chip capable of operating in the 37GHz~40GHz band were arranged in a 1x5 array. While the LF and HF ceramic chips share the same material and manufacturing process, the antenna size is designed differently according to the frequency.

Figure 3 illustrates the manufacturing process of the 5G ceramic antenna. The process begins with the mixing of ceramic powder in the first step, followed by a heat treatment in the second step to create a ceramic substrate. Subsequently, a via hole is formed on the ceramic substrate using a laser in the fourth step, and the hole is filled with Ag-paste in the fifth step. Electrodes are then formed through screen printing in the sixth step. Electroplating is performed in the seventh step, and multiple ceramic substrates are laminated in the eighth step. Next, the laminated ceramic substrates are diced to create individual 5G ceramic antenna chips in the ninth step. The antenna characteristics of these chips are evaluated in the tenth step to distinguish good chips from bad ones. The entire manufacturing process consists of a total of 12 steps, which include quality inspection and shipment inspection in the 11th step, and shipment in the 12th and final step. The overall defect rate across all 12 processes was approximately 7.1%, and Fig. 4 presents the relative defect rate in each process. The laser punching process (process No. 4) had the highest relative defect rate, with a defect rate of 35.2%. The laser filling process (process No. 5) ranked third, with a defect rate of about 14.1%. Processes 1, 2, and 12 were excluded from Fig. 4 because they had a defect rate of 0%. Due to the lack of a traceable change history of data between each process, it is currently challenging to identify the exact process in which a defect occurred.

2-2 Blockchain and smart contracts

Blockchain was initially applied to Bitcoin, a cryptocurrency introduced by Satoshi Nakamoto [1], and later gained widespread recognition, paving the way for the emergence of various other electronic currencies such as Ethereum.

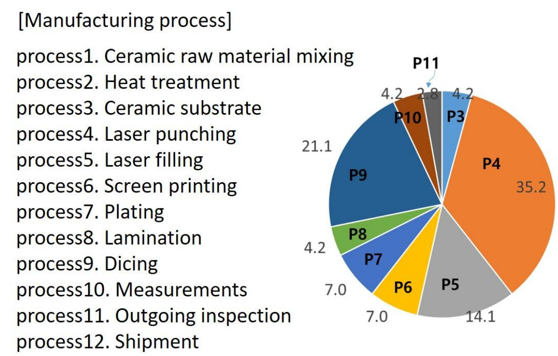

Fig. 4. Relative defect rate (%) of 5G ceramic chip antenna manufacturing process

At its core, blockchain is a shared ledger technology capable of storing verified transaction data immutable [8]. Due to its reliability, blockchain has been referred to as a trustworthy 'trust machine' [24]. This ledger technology is considered a key element of the future, as it serves as a dependable record of business activities at a fundamental level. In manufacturing companies, establishing trust between each process is crucial for ensuring product quality, manufacturing efficiency, and timely delivery.

Unlike traditional centralized systems, blockchain operates as a decentralized network where all transactions are verified and recorded on a public ledger, shared by all participants. This architecture enables direct peer-to-peer transactions without the need for intermediaries, ensuring transparency and integrity throughout the process. Transactions on the blockchain are grouped into blocks, which are securely linked to one another through encryption, forming a continuous chain. As each block is linked to its preceding block, altering data in any previous block would require modifying all subsequent blocks, making the data on the blockchain immutable.

Moreover, blockchain leverages distributed computing technology, allowing all participants in the network to simultaneously verify and store transaction details. This ensures that even if the nodes in the network are widely dispersed, transactions can be securely processed. Consequently, blockchain has become a highly secure platform and finds applications in diverse fields. Beyond serving as a simple transaction record, blockchain is expected to evolve into a key technology of the future. The applications of blockchain span various domains, including smart contracts, distributed networks, car sharing, and health information sharing. With its potential to bring about innovative changes, blockchain technology holds promise for transformative advancements in different industries [25]-[27].

Smart contract, a computer transaction protocol proposed by Nick Szabo in 1994 [8], is a program designed to automatically execute the terms of a contract, operating on the foundation of blockchain technology. By utilizing smart contracts, contracting parties can enhance reliability and reduce risks that may arise during the contract signing and fulfillment process. Smart contracts are widely applied in various fields to address the limitations of traditional contracts while reinforcing security and transparency. In the financial sector, smart contracts are employed to automate processes such as financial product transactions and insurance claims, thereby increasing operational efficiency. Similarly, in the manufacturing sector, smart contracts are utilized to improve productivity and quality by effectively managing each stage of product production. Additionally, smart contracts find applications in diverse domains such as smart cities, healthcare, real estate, and the IoT. The potential of smart contracts in various fields is expected to grow further in the future [28]-[31].

The adoption of smart contracts offers a solution to the issue of low reliability in existing digital protocols, as it addresses challenges related to easy copying and counterfeiting. In the context of 5G ceramic antenna manufacturing, smart contracts can be employed to program and store conditions that each process product must meet to progress to the next step. When all conditions are satisfied, the smart contract can automatically trigger the transition to the subsequent stage. This represents a significant improvement over the traditional approach, where a failure in any intermediate process would necessitate starting the entire process from scratch. By minimizing such costly failures, this study aims to enhance the efficiency and effectiveness of the 5G ceramic antenna manufacturing process.

2-3 Blockchain Applications in 5G Communication and Manufacturing Industries

In both the manufacturing industry and the field of 5G communication, blockchain technology has gained significant attention for its potential to address various challenges and enhance processes. In the manufacturing industry, blockchain is being actively explored to tackle issues of transparency, efficiency, and safety. Especially in the realm of electronic parts, considerable research efforts are focused on leveraging blockchain to optimize manufacturing and supply processes [32]-[35]. This involves establishing transparent systems by recording crucial information, such as the history and origin of parts, on the blockchain. Such systems proactively prevent and resolve potential supply chain issues. Additionally, blockchain's integration with IoT sensors is being examined to detect and prevent defects during manufacturing and enable rapid responses. This synergistic approach fosters trust between manufacturers and customers and facilitates swift resolution of production-related problems. Furthermore, blockchain prevents counterfeiting and enhances safety by recording parts' histories, fostering secure processes [36]-[39].

Similarly, in the 5G communication field, blockchain is deployed in various ways to bolster security and efficiency. One noteworthy application is enhancing the security of 5G networks through the decentralized distribution network structure of blockchain. This can thwart hacker invasions and enhance authentication and encryption of devices and data. Additionally, blockchain aids in managing 5G infrastructure resources and data, leading to cost-efficient infrastructure construction and maintenance. Smart contracts are also being developed to automate processes in deploying and managing 5G services, conserving time and resources. Moreover, blockchain ensures data integrity and guards against tampering or counterfeiting, addressing data security concerns in 5G communication. Finally, the convergence of blockchain and IoT in 5G communication paves the way for innovative service models, such as smart cities [40]-[44].

2-4 Challenges and Solutions in Applying Blockchain to 5G Ceramic Antenna Manufacturing

While research on applying blockchain to the 5G communication field is extensive, its specific application in 5G ceramic antenna manufacturing remains limited. Within this industry, several process-related challenges are evident. The supply chain of materials, often globally sourced, can lead to stability issues. Complex manufacturing processes and technical uncertainties hinder quality control and process improvement. Technical requirements for 5G ceramic antennas are demanding, and shortages in skilled labor can disrupt production.

To address these issues, effective measures are proposed. These include establishing transparent and stable supply chains, implementing blockchain for transparent

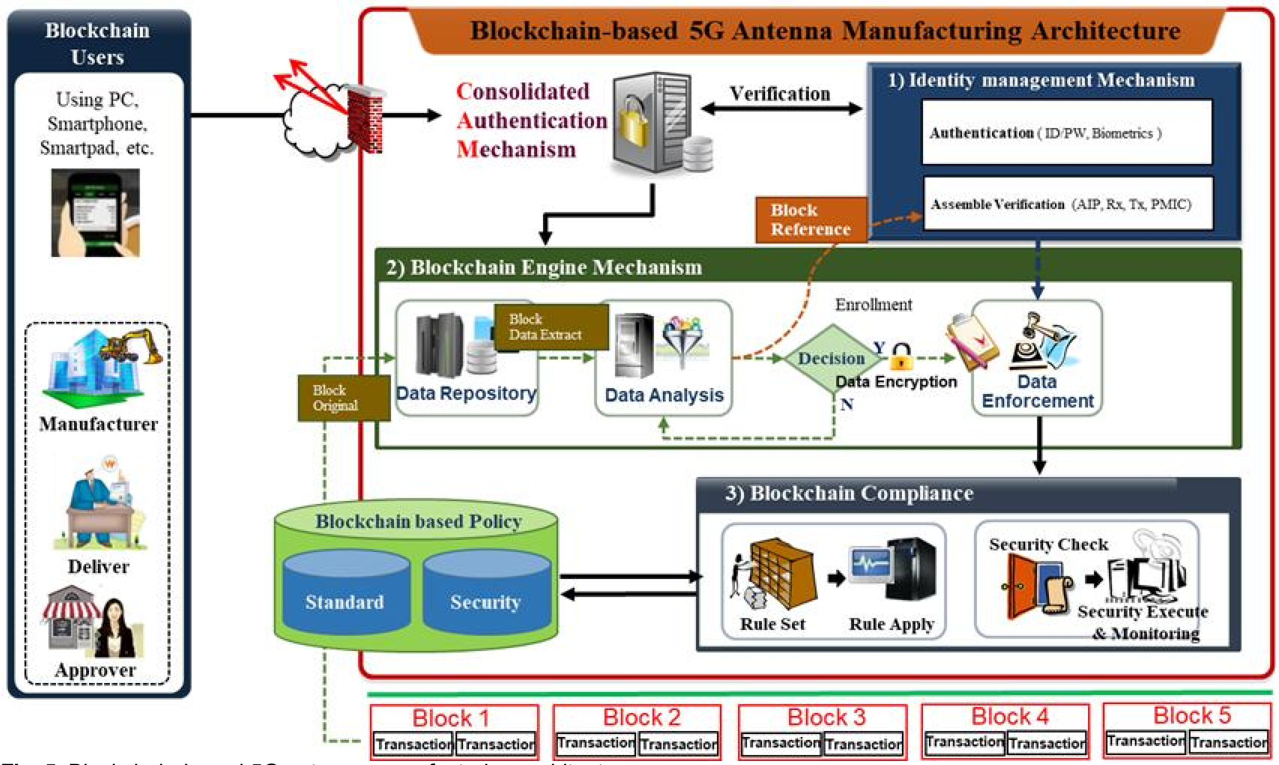

Fig. 5. Blockchain-based 5G antenna manufacturing architecture

process management, and ensuring a skilled workforce. Furthermore, blockchain's application can reduce defect rates by enabling traceability and identification of root causes through smart contracts. These contracts facilitate swift responses to problems, enhancing productivity and product quality in the electronic parts manufacturing industry, including 5G ceramic antenna production. Overall, blockchain's potential to revolutionize communication and manufacturing processes is evident, but challenges such as speed, security, cost, and standardization require careful consideration and ongoing research to ensure successful integration [32-33], [35], [45]-[46].

Ⅲ. Blockchain based 5G antenna manufacturing (B-5GAM) architecture

To address the challenges in 5G ceramic antenna manufacturing, we propose a blockchain-based 5G ceramic antenna manufacturing (B-5GAM) architecture, as depicted in Fig. 5. The current process faces significant costs and time delays when defects occur, necessitating the scrapping of the entire process and starting anew. To resolve this issue, we introduce a mechanism to identify and rectify defects by pinpointing the specific process where they occurred, which is currently challenging. Moreover, ensuring security at each process stage is crucial, yet it has been noted that security measures between manufacturers, transporters (deliverers), and approvers are not well-maintained. Consequently, the major concerns in the 5G antenna manufacturing process are cost, security, and efficiency.

To tackle these problems, the B-5GAM architecture offers the following key features:

1) Identity Management Mechanism: Utilizing blockchain, this mechanism manages and authenticates user identities, such as manufacturers, deliverers, and approvers. It ensures reliable identification and precise control over each user's authorization and role within the blockchain network.
2) Blockchain Engine Mechanism: This mechanism leverages smart contracts and blockchain engines to enhance the efficiency of the antenna manufacturing process. Smart contracts execute automated contract logic and can be programmed with specific conditions

and rules for various stages of production. This increases transparency and accuracy, while minimizing human intervention, enabling quicker decisions and execution.

3) Blockchain Compliance: This feature utilizes blockchain to enforce policies and regulations during the 5G ceramic antenna manufacturing process. All parties involved, including manufacturers, deliverers, and approvers, must adhere to the rules and protocols established on the blockchain network. This ensures transparency, reliability, and compliance with relevant regulations.

The B-5GAM architecture is designed to optimize the manufacturing process by employing blockchain and smart contracts to address cost, security, and efficiency concerns effectively. The Consolidated Authentication mechanism, as illustrated in Fig. 5, serves the function of authenticating users' identities based on the blockchain. Manufacturers, deliverers, and approvers undergo credible authentication through the blockchain, granting them the authority to participate in the manufacturing process. The Block data extract function is responsible for extracting essential data from the blockchain. During the manufacturing process, data is recorded on the blockchain, and necessary information can be obtained by extracting it. The data repository securely stores the data recorded on the blockchain. The distributed storage of manufacturing process data in the blockchain prevents tampering and ensures data reliability and integrity. The data analysis function derives valuable insights by analyzing the data generated during the manufacturing process. Data analysis is employed to improve efficiency and predict defects, providing rapid and accurate analysis results based on the data stored in the blockchain.

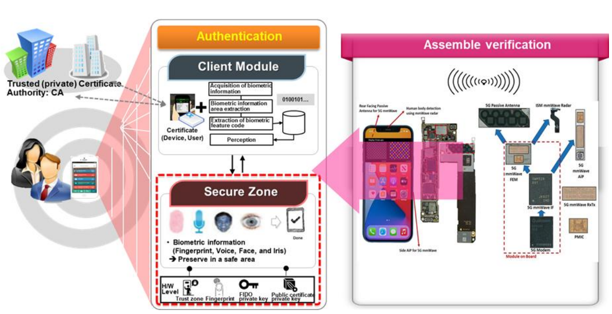

Fig. 6. Integrated user authentication for user protection in blockchain-based distributed network

Enrollment is the process of registering new users on the blockchain network. Manufacturers, deliverers, or approvers are registered as new users, enabling them to actively participate in the blockchain network. Data encryption enhances the security of the data generated in the manufacturing process. Encrypted data is securely stored on the blockchain, preventing unauthorized access. Data enforcement involves the implementation of strict rules and policies on the data stored in the blockchain. This ensures the integrity and security of the data, with stringent rules being applied and monitored within the blockchain network. The Blockchain-based policy also encompasses standards and security. To achieve this, functions such as rule set, rule apply, security check, security execution, and monitoring are utilized. Standards are applied to maintain consistency and efficiency in the manufacturing process, while enhanced security mechanisms ensure the stability of the blockchain network. Rules ensure compliance with established policies, and security checks and execution verify and maintain the network's safety. Through these features, the overall B-5GAM architecture ensures data safety, efficiency, and security, while maintaining transparency and consistency in the 5G ceramic antenna manufacturing process.

To address the challenges inherent in the 5G ceramic antenna manufacturing process, we propose a solution depicted in Figure 6: a blockchain-based distributed network with integrated user authentication. This architecture is tailored specifically for the context of 5G ceramic antenna production and ensures robust user protection. Within this proposed architecture, a critical phase known as "Assemble Verification" takes center stage. The Assemble Verification step involves the assembly and verification of various components that constitute the ceramic antenna. To ensure the security and integrity of this process, user authentication and component verification are tightly integrated. This integration safeguards the legitimacy of users participating in the manufacturing process and establishes the authenticity of the components being assembled. Authentication of ceramic antenna components is a pivotal aspect of this solution. Throughout the manufacturing journey, a series of meticulous steps are undertaken. These steps encompass the acquisition of certificates for both devices and users, as well as the collection of biometric data. The process involves extracting the biometric information area, isolating the biometric feature code, and engaging in perceptual analysis. This comprehensive process serves to verify the genuine identity of each ceramic antenna component and confirm the authenticity of the associated information.

For an added layer of security, a dedicated secure zone is implemented to enhance the biometric authentication process. A variety of robust biometric methods, such as fingerprint, voice, facial, or iris recognition, can be applied during ceramic antenna manufacturing. By employing these sophisticated biometric techniques, the authentication of user identities is fortified, ensuring that only authorized individuals engage in the manufacturing process. Central to the proposed solution is the pivotal role played by the Assemble Verification step. This step effectively addresses two crucial aspects: user identity authentication and component authentication through biometrics. By verifying the identity of both users and components, a secure and reliable manufacturing environment is established. These integrated measures elevate the security and integrity of the entire 5G ceramic antenna manufacturing process. The solution we present involves a blockchain-based distributed network with integrated user authentication, specifically designed to overcome challenges in 5G ceramic antenna manufacturing. The proposed architecture not only safeguards user identities but also ensures the legitimacy of antenna components through robust biometric authentication. This approach fosters a highly secure and dependable manufacturing process, contributing to the overall integrity and quality of 5G ceramic antenna production.

Incorporated within the text, Fig. 7 presents an elaborate depiction of the blockchain engine mechanism employed during the manufacturing process of 5G ceramic antennas.

This mechanism comprises a sequence of steps, namely data classification, reconstruction of sensitive/confidential data, evaluation, and confirmation, as elaborated below:

1) Data Classification: The data classifier accepts data related to the manufacturing of 5G ceramic antennas, such as antenna components or data generated during the manufacturing process, along with the original source data stored on the blockchain. The data classifier analyzes and categorizes this data based on its characteristics and types. This step ensures proper data management by organizing the data generated during the manufacturing process into appropriate categories.

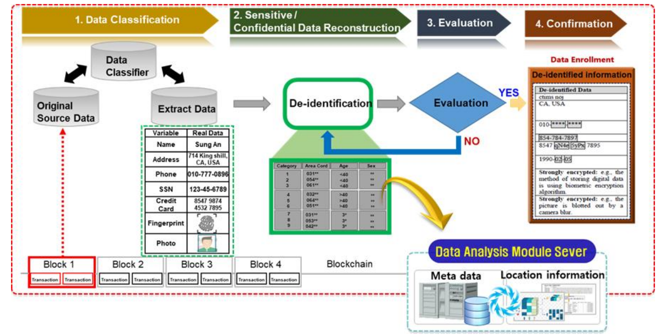

Fig. 7. Blockchain engine mechanism for verifying and validating data shared in a blockchain before uploading it to the blockchain

2) Sensitive/Confidential Data Reconstruction: In this step, data classified as sensitive or confidential by the data classifier is securely reconstructed. For instance, crucial data like personal information or patent-related details is anonymized during reconstruction. By doing so, the privacy and integrity of important data generated during the 5G ceramic antenna manufacturing process are preserved.

3) Evaluation: The data that has undergone classification and sensitive/confidential data reconstruction is subjected to evaluation to assess its validity and reliability. This evaluation process checks the accuracy, completeness, consistency, and reliability of data related to 5G ceramic antenna manufacturing. It ensures that the data generated during the manufacturing process is trustworthy and reliable.

4) Confirmation: Upon evaluation, the data proceeds to the de-identification process, where its completeness and reliability are finally verified before being uploaded to the blockchain. This step ensures that the data stored on the blockchain network is verified and securely shared, guaranteeing the integrity of the data related to 5G ceramic antenna manufacturing.

Figure 7 demonstrates the comprehensive process of data classification, sensitive/confidential data reconstruction, evaluation, de-identification, and verification in the manufacturing process of 5G ceramic antennas. Through this mechanism, the reliability and integrity of the data are verified before securely uploading it to the blockchain. By employing this process, data management and security are reinforced during the manufacturing of 5G ceramic antennas, leading to efficient data sharing and a secure manufacturing process through blockchain technology. Legal validity and blockchain compliance in the blockchain environment, centered on legal and policy analysis, are shown in Fig. 8. The figure analyzes various legal aspects concerning data processing to enhance the efficiency of the 5G ceramic antenna manufacturing process. It categorizes the key stages of data processing, including Collection, Retention, Provision, and Disposal, which represent significant activities involved in the 5G ceramic antenna manufacturing process. In addition, Fig. 8 incorporates elements relevant to legal aspects, such as Restriction on sensitive information, Age restriction, and Notice. These elements reflect legal regulations and policies associated with data processing. For instance, "Restriction on Sensitive Data" outlines rules for handling sensitive data in compliance with personal data protection laws. By examining the feasibility and regulatory compliance of data processing in the 5G ceramic antenna manufacturing process through legal aspects and policy analysis, Figure 8 ensures efficient implementation of data processing while adhering to legal requirements. This approach reinforces data protection and privacy during the manufacturing process, ensures adherence to relevant legal restrictions, and establishes a secure manufacturing environment. Overall, Figure 8 presents a method to enhance the efficiency of the 5G ceramic antenna manufacturing process through a thorough analysis of legal aspects and policies. This approach enables the creation of a safe and reliable manufacturing environment for 5G ceramic antennas while maintaining compliance with legal regulations and policies.

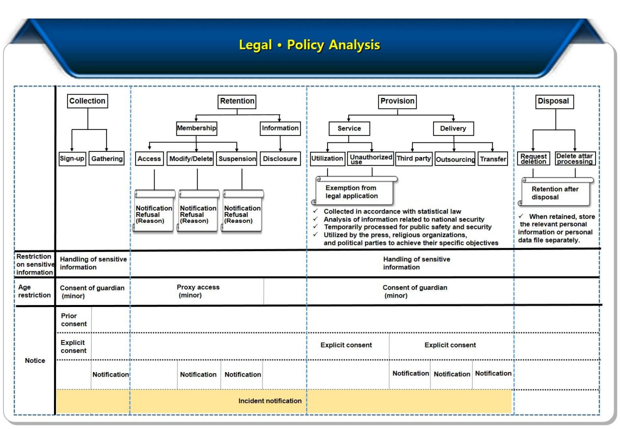

Fig. 8. Blockchain Legal validity and blockchain compliance in the blockchain environment

```
pragma solidity ^0.8.0;

contract BiddingSystem {

   struct Proposal {
      uint completion;
      uint dueDate;
      uint price;
      address bidder;
      bool isApproved;
   }

   Proposal[] public proposals;
   address public owner;

   constructor() {
      owner = msg.sender;
   }

   function createProposal(uint _completion, uint _dueDate, uint _price)
public {
      require(msg.sender != owner, "Owner cannot create proposal");
      Proposal memory newProposal = Proposal({
         completion: _completion,
         dueDate: _dueDate,
         price: _price,
         bidder: msg.sender,
         isApproved: false
      });
      proposals.push(newProposal);
   }

   function approveProposal(uint index) public {
      require(msg.sender == owner, "Only owner can approve proposal");
      require(index < proposals.length, "Invalid proposal index");
      proposals[index].isApproved = true;
   }

   function getProposal(uint index) public view returns (uint, uint, uint,
address, bool) {
      require(index < proposals.length, "Invalid proposal index");
      return (proposals[index].completion, proposals[index].dueDate,
proposals[index].price, proposals[index].bidder, proposals[index].isApproved);
   }

}
```

Fig. 9. Algorithm for applying blockchain to the 5G ceramic antenna manufacturing process for the validation of the proposed concepts in the B-5GAM architecture

To validate the concepts proposed in the B-5GAM architecture, the algorithm for applying blockchain to the 5G ceramic antenna manufacturing process is presented in Fig. 9. The provided code implements a smart contract called "BiddingSystem" in the Solidity language. "BiddingSystem" is the name of the smart contract applied to the 5G ceramic antenna manufacturing process. This contract provides functions for creating proposals, managing proposal information, and querying proposal details. The "Proposal" structure contains information about each proposal, including variables such as "completion," "dueDate," "price," "bidder," and "isApproved." "Completion" represents the status of proposal completion. "DueDate" denotes the deadline for the proposal, and "price" indicates the proposed price. "Bidder" stores the address of the account that submitted the proposal, and "isApproved" is a Boolean value that determines if the proposal has been approved. "Proposals" is an array of "Proposal" structures, where all proposals are stored and managed. This space gathers various plans or proposals presented for public safety or interest. Each proposal may be formulated individually to achieve a specific goal or solve a problem, and it could be approved or reviewed by the manufacturer, carrier, or authorizing authority. "Owner" represents the address of the smart contract's owner and is set to the account that deployed the contract. The "Constructor" is the constructor of the "BiddingSystem" contract, initialized by assigning the account that deployed the contract (msg.sender) to the "owner." The "createProposal" function allows the creation of a new proposal. Only non-owner accounts can create proposals. The function receives information such as "completion," "dueDate," and "price," creates a new "Proposal" structure, and adds it to the "proposals" array. The "approveProposal" function is used to approve a proposal, and only the owner can do this. The "getProposal" function retrieves the proposal information for a specific index in the "proposals" array. The algorithm presented in Fig. 9 can be applied to the 5G ceramic antenna manufacturing process, and the process of creating, approving, and querying proposals can be efficiently managed through smart contracts. By utilizing blockchain, this approach enables transparent and reliable data processing in the 5G ceramic antenna manufacturing process.

The code model of the 5G ceramic antenna manufacturing process, which abstracts the manufacturing process using smart contracts, is presented as a smart contract in Fig. 10. Each process is represented by a SmartContract object, and the entire manufacturing process is represented by an instance of the ManufacturingProcess class. The SmartContract class serves as an abstraction of a smart contract. In the 'init method,' the name and address of the smart contract are initialized, and the current state is set to 'Not started.' The 'start_process method' changes the status of the smart contract to 'In progress,' and the 'complete_process method' changes the status to 'Completed.' The commented-out part represents the code that sends the actual transaction to the Ethereum blockchain. The ManufacturingProcess class represents the entirety of the manufacturing process. It creates a SmartContract instance for every process provided in the 'init method' and saves it in advance.

Table 1. Smart contract configuration and weight conditions in blockchain-enable 5G antenna manufacturing process

CATEGORY	CRITERIA	INDEX	SCORE	WEIGHT (%)
Security	Integrity	Present / absent	20	30
	Confidentiality	Present / absent	20	
	Transparency	High / low	10	
	Security test	Present / absent	30	
	Vulnerability Assessment	Conducted / not conducted	20	
Standard & Law regulation	Compliance	Yes / no	20	20
	Check	Yes / no	20	
	Monitoring	Yes / no	30	
	Enforcement	Yes / no	20	
	Auditing	Yes / no	10	
Efficiency	Unit gain	> 3dBi	30	50
	Integration gain	> 10dBi	10	
	System gain	> 10dBi	20	
	Performance test	> 1ms	40	

The 'start_process,' 'complete_process,' and 'get_status methods' are used to initiate, complete, or check the status of a specific process. The final part of the code demonstrates an example of creating a manufacturing process with 12 processes, starting and completing the first process. This code illustrates how each step in the manufacturing process can be modeled as a smart contract, showcasing how blockchain can transparently track the status of each process, quickly detect anomalies, and increase overall efficiency. The verification of anticipated effects was substantiated through a comprehensive analysis of security measures, adherence to relevant standards and regulations, and an evaluation of manufacturing efficiency specific to 5G ceramic antennas. A formulated cost equation was developed, as shown in Equation (2):

$$\begin{aligned} Cost = &(w1 * Security) \\ &+ w2 * Standard\ Law\,Regulation) \\ &+ (w3 * Efficiency) \\ &+ (w4 * Additional\,Factor) \end{aligned} \tag{2}$$

```
# In order to connect to the Ethereum blockchain, we need the web3 library
# You would typically import it at the top of your script
# import web3

# Define a class for Smart Contracts
class SmartContract:
  def __init__(self, name, address):
    self.name = name
    self.address = address
    self.status = "Not started"

  def start_process(self):
    self.status = "In progress"
    print(f"{self.name} has started.")

    # Here is where you would connect to the blockchain and start the process
    # Note that this code is just a simulation and doesn't actually connect to the blockchain
    # Here is how you would do it in a real-world scenario:
    # web3.eth.sendTransaction({
    #    "from": self.address,
    #    "to": "0x1234567890abcdef1234567890abcdef123456789",  # This would be the manufacturer's address
    #    "value": 1,  # This value would depend on your specific use case
    # })

  def complete_process(self):
    self.status = "Completed"
    print(f"{self.name} has completed.")

    # web3.eth.sendTransaction({
    #    "from": self.address,
    #    "to": "0x1234567890abcdef1234567890abcdef123456789",  # This would be the manufacturer's address
    #    "value": 1,  # This value would depend on your specific use case
    # })

# Define a class for the Manufacturing Process
class ManufacturingProcess:
  def __init__(self, processes):
    self.processes = {name: SmartContract(name, "0x8765432109876543210987654321098765432l0") for name in processes}

  def start_process(self, process_name):
    if process_name in self.processes:
      self.processes[process_name].start_process()
    else:
      raise ValueError("Invalid process name")

  def complete_process(self, process_name):
    if process_name in self.processes:
      self.processes[process_name].complete_process()
      if process_name == list(self.processes.keys())[-1]:  # If this is the last process
        print("All processes have completed!")
    else:
      raise ValueError("Invalid process name")

  def get_status(self, process_name):
    if process_name in self.processes:
      return self.processes[process_name].status
    else:
      raise ValueError("Invalid process name")

# Define the manufacturing process
manufacturing = ManufacturingProcess(["Process1", "Process2", "Process3", "Process4", "Process5",
                   "Process6", "Process7", "Process8", "Process9", "Process10", "Process11", "Process12"])

# Start and complete each process
for process_name in ["Process1", "Process2", "Process3", "Process4", "Process5",
          "Process6", "Process7", "Process8", "Process9", "Process10", "Process11", "Process12"]:
  manufacturing.start_process(process_name)
  manufacturing.complete_process(process_name)
```

Fig. 10. Conceptual pseudo-code representation of 5G ceramic antenna manufacturing process leveraging smart contracts on a blockchain architecture

Table 2. Expected benefits of security, standard & law compliance, and efficiency in blockchain-enabled 5G antenna manufacturing process

CATEGORY	CRITERIA	AS-IS	B-5GAM
Security	Integrity	O	O
	Confidentiality	O	O
	Transparency	X	O
	Security test	X	O
	Vulnerability Assessment	X	O
Standard & Law regulation	Compliance	O	O
	Check	O	O
	Monitoring	X	O
	Enforcement	O	O
	Auditing	X	O
Efficiency	Unit gain	O	O
	Integration gain	X	O
	System gain	X	O
	Performance test	X	O

Here, the variables $w1$, $w2$, $w3$, and $w4$ represent the weights assigned to each corresponding factor, and these weights are assigned non-negative values. The configuration parameters and weight conditions used in the 5G antenna manufacturing process integrated with blockchain are illustrated in Table 1. Smart contracts, operating automatically through blockchain technology, play a pivotal role in enhancing manufacturing transparency and efficiency. By setting these values, it becomes possible to discern how smart contracts are structured and how weight conditions are applied, thereby understanding the relative impact of different weight factors on the overall cost assessment.

In this formulation, the security factor serves as an indicator of security enhancement, while the Standard & Law Regulation factor reflects the extent of compliance with pertinent industry standards and regulations. The Efficiency factor encompasses indicators of productivity, work efficiency, and resource utilization. Additionally, the Additional Factor accounts for supplementary elements that require consideration. Utilizing this comprehensive formula enables the quantification of each factor's contribution, with the assigned weights, to the overall cost calculation. This approach allows an insightful analysis of the cost implications of each individual factor, based on their respective significance. For instance, the security indicators entail aspects such as encryption technology, access control, and data integrity. The evaluation of Standard & Law compliance involves the assessment of applicable regulations and standards, leading to the establishment of relevant indicators like compliance confirmation, certification and standard adherence, and adherence to environmental regulations. Efficiency indicators encapsulate diverse elements including productivity, work efficiency, and optimal resource utilization. Through the application of this derived formula, it becomes feasible to analyze the influence of each individual factor on the overall cost, achieved by substituting the specific values of corresponding elements into the formula. Notably, an enhancement in efficiency results in a reduction of costs, indicating a positive impact on overall expenses.

Table 2 illustrates the contrasts and anticipated benefits when comparing the conventional 5G antenna manufacturing process with the process integrated with B-5GAM, as evaluated through a weighted cost assessment. In the traditional 5G antenna manufacturing approach, monitoring the progression of individual stages and tracking the historical alterations of data poses challenges. However, the integration of B-5GAM brings forth substantial improvements by leveraging blockchain technology to transparently document and unveil the history of data modifications. This heightened transparency and reliability allow both manufacturers and customers to observe the manufacturing journey in real-time, bolstering data integrity and elevating overall dependability.

By embracing B-5GAM, the automation of operations through smart contracts becomes feasible. This reduction in manual intervention translates to saved manpower and reduced time consumption, expediting the identification and resolution of issues during production. Such automated processes fuel enhanced productivity, cost efficiency, and facilitate swift market entry, ensuring timely production of accurate products. B-5GAM further streamlines regulatory compliance verification through blockchain's transparent structure and data integrity. Regulators can seamlessly access manufacturers' data for scrutiny and monitoring, empowering antenna producers to efficiently fulfill regulatory prerequisites and secure certifications. This dynamic fosters heightened trustworthiness and competitiveness within the market. The utilization of blockchain encryption technology within B-5GAM bolsters data security. Manufacturers can securely store and share crucial process details and technical expertise while erecting barriers against unauthorized external access. This mitigation of information leakage risk fortifies intellectual property rights and sustains data integrity. In essence, the 5G ceramic antenna manufacturing process enhanced by B-5GAM cultivates an environment characterized by transparency, efficiency, and security. The amalgamation of blockchain technology and smart contracts addresses production-related hurdles, amplifies productivity, ensures regulatory alignment, and reinforces trustworthiness and competitive prowess within the market domain. Furthermore, the preservation of data security and integrity stimulates innovation and progress within the 5G ceramic antenna manufacturing sector, cascading into positive ramifications for overarching growth and advancement across the manufacturing landscape.

Ⅳ. Conclusion and Future Research Plans

4-1 Key Insights and Implications

This paper proposes a blockchain-based 5G ceramic antenna manufacturing (B-5GAM) architecture to address process issues in 5G ceramic antenna manufacturing and introduces a plan to leverage blockchain and smart contracts. The integration of blockchain and smart contracts in the 5G telecommunications field offers a highly promising approach to resolve manufacturing process challenges and enhance transparency, safety, and efficiency. The application of blockchain in the 5G ceramic antenna manufacturing process demonstrated notable improvements in security, efficiency, and reliability. By implementing blockchain technology, we successfully achieved transparent data management and process tracking throughout the manufacturing stages. The smart contracts for proposal generation, approval, and inquiry provided systematic monitoring of each manufacturing step, offering trustworthy data records via the blockchain. Consequently, this approach strengthened trust between manufacturers, deliverers, and approvers, facilitating quality control and efficient production. Moreover, we ensured compliance with legal requirements in the 5G ceramic antenna manufacturing process by analyzing legal feasibility and blockchain compliance. By incorporating policies such as data restrictions, age limitations, and notices at the data processing stage, data protection and personal information security were significantly reinforced.

As a conclusion, the application of blockchain technology enhanced the 5G ceramic antenna manufacturing process, making it more efficient and secure. Therefore, integrating blockchain into the 5G ceramic antenna manufacturing process represents a strategic and essential choice for future advancements in communication technology. The adoption of blockchain facilitated reduced defect rates, cost savings, and enhanced reliability through distributed and recorded management of production information for each manufacturing stage on the network.

4-2 Further Research

Based on the findings and recommendations of this study, it is imperative to conduct a pilot project applying blockchain and smart contracts in the future for 5G ceramic antenna manufacturing. This pilot project will allow us to validate the effectiveness of addressing problems and enhancing productivity in the actual production process. Additionally, through these practical applications, the potential and feasibility of employing blockchain and smart contracts in other electronic parts manufacturing industries, not just limited to 5G ceramic antenna manufacturing, can be demonstrated.

Furthermore, future research directions should explore the applicability of blockchain and smart contracts in various electronic parts manufacturing industries, extending beyond 5G ceramic antenna manufacturing. Additionally, research should be conducted on the advancement of security and authentication technologies utilizing blockchain and smart contracts in the context of 5G communication. This will lay the groundwork for broader adoption of blockchain and smart contracts in the 5G communication domain. Collaboration among diverse stakeholders such as government agencies, industry associations, academia, and companies is essential to build an ecosystem for innovation and development in 5G ceramic antenna manufacturing through blockchain and smart contracts. Such collaboration will drive successful advancements in the field of 5G communication and foster the digital transformation of the manufacturing industry. Through further research and real-world applications, innovative changes can be achieved in the electronic component manufacturing industry, including 5G ceramic antenna manufacturing. This will significantly contribute to enhancing the performance of 5G communication by fully harnessing the potential of blockchain and smart contracts.

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안 성 용 (Sung Yong An)
1996년 BS In Education of Physics at Kookmin University, Korea
1998년 MS in Physics at Koomin University, Korea
2002년 Ph.D. in Physics at Koomin University, Korea
2002년~2003년 Post-Doctor at Colorado State University, USA
2003년~2004년 Research Professor at Kookmin University, Korea
2022년 Master of Business Administration at Aalto University, Finland
2004년~현재 Principal Engineer, Samsung Electro-Mechanics, Korea
2022년~현재 Franklin University Switzerland Candidate DBA, Switzerland
2022년~현재 Seoul Business School, aSSIST University Candidate Ph.D in Business, Korea
※관심분야 : Business 5G antenna, Blockchain, Smart Contract, Efficiency and Security

홍 승 필 (Seng-Phil Hong)
1993년 BS in Computer Science Indiana State University, USA
1994년 MS in Computer Science Ball State University, USA
1997년 Ph.D. CS, Illinois Institute of Technology, USA
2003년 Ph.D. in Computer Science KAIST, Korea.
1997년~2005년 LG-CNS, Inc Korea
2005년~2019년 Professor. Sungshin University, Korea.
2019년~2022년 President CEO / Senior Adviser of HANCOM WITH, Korea
2022년~현재 Professor, Seoul of AI, aSSIST University, Korea.
※관심분야 : Business 5G antenna, Blockchain, Smart Contract, Efficiency and Security

구이, 엔가요 (Guy, Ngayo)
1993년 BA in Psychology and Sociology, at University of Rouen, France
1994년 MA in Management at University of Montreal, Canada
2004년 Master of Business Administration at Thunderbird Graduate School of Management, USA
2019년 Doctoral Business Administration at Toulouse Business School, France
1997년~2005년 Andersen Consulting-Accenture, France
2005년~2007년 Trade Marketing Director, Hilti France, France
2007년~2010년 Global Senior Product Manager, Hilti Worldwide Headquarter, Liechtenstein
2010년~현재 Founder and managing director of Verticacoaching, Switzerland
2010년~현재 Professor, Business School Lausanne, Switzerland
2015년~현재 Professor, Paris School of Business, France
2017년~현재 Professor, Toulouse Business School, France
2020년~현재 Founder and managing Director of Swiss Institute for Leadership, Switzerland
※관심분야 : Executive Coaching, Cross-functional expertise and experience, Strategic Business Planning, Research skills