MANTECH Publications

Journal of Wireless Communication, Network and Mobile Engineering Technology
Volume 11, Issue 1, January-April 2026
ISSN: 3049-3137 (Online)

Integrated Sensing and Communication (ISAC)

Vaishnavi Shinde[1], Yashshree Jadhav[2]

Assistant Professor[1], Student[2]

Department of Electronics & Telecommunication Engineering

Dr. Daulatrao Aher College of Engineering, Karad (Shivaji University)

Email ID: *vaishnavi.shinde57@yahoo.com[1]*

DOI: *https://doi.org/10.5281/zenodo.19639470*

ABSTRACT

The next generation wireless networks such as 6G are expected to support extremely high data rates, ultra-low latency and intelligent services. At the same time many modern applications require environmental awareness and accurate sensing capabilities. Traditionally, communication and sensing systems were designed separately, where radar systems were used for sensing and wireless networks were used only for data transmission. However this separation leads to inefficient use of spectrum and hardware resources. Integrated Sensing and Communication (ISAC) has emerged as a promising technology that combines both sensing and communication functionalities into a single system.

ISAC enables wireless devices to simultaneously transmit information and sense the surrounding environment by using shared waveforms, spectrum and hardware. This integration can significantly improve spectrum efficiency, reduce deployment cost and enable new applications such as autonomous driving, smart cities, drone networks and industrial automation. In recent years, researchers have proposed various system architectures, waveform design techniques and signal processing algorithms to implement ISAC in future networks.

This paper presents a comprehensive review of Integrated Sensing and Communication technology. The paper first explains the basic concept and motivation behind ISAC. Then the system architecture and different design approaches are discussed. Various enabling technologies such as millimeter-

wave communication, massive MIMO and artificial intelligence are also explained. In addition, major applications and technical challenges of ISAC are presented. Finally the paper discusses future research directions for the development of efficient ISAC systems in next generation wireless networks.

KEYWORDS: *Integrated Sensing and Communication, 6G Networks, Radar Communication Integration, Wireless Sensing, Spectrum Efficiency, Smart Environment*

INTRODUCTION

Wireless communication technologies have evolved rapidly over the past few decades. From the early analog cellular systems to modern high-speed 5G networks, each generation has introduced new capabilities and services. The upcoming sixth generation (6G) wireless systems are expected to support extremely high data rates, ultra-reliable connectivity and intelligent network operation.

Apart from communication services, future wireless networks are also expected to provide sensing capabilities. Sensing refers to the ability of a system to detect objects, measure distance, estimate movement and obtain information about the surrounding environment. Traditionally sensing tasks were performed by radar or specialized sensors while communication systems were mainly used to transmit information between devices.

However, maintaining separate systems for communication and sensing leads to inefficient use of spectrum and hardware resources. Both radar and communication systems often operate in similar frequency bands and require similar signal processing techniques. Because of this similarity, researchers started exploring the possibility of integrating these two functionalities into a single system.

Integrated Sensing and Communication (ISAC) is a new paradigm that combines wireless communication and sensing into one unified framework. In ISAC systems, the transmitted signals can carry communication data while also being used for sensing the environment. This dual functionality allows better utilization of spectrum and infrastructure.

ISAC has gained significant attention in recent years because of its potential applications in areas such as autonomous vehicles, smart cities, drone networks, industrial automation and security monitoring. Many researchers believe that ISAC will be one of the important technologies for 6G networks.

The aim of this paper is to review the basic principles, system architectures, enabling technologies, applications and challenges of ISAC systems.

MOTIVATION FOR INTEGRATED SENSING AND COMMUNICATION

The idea of integrating sensing and communication functions into a single wireless system has received considerable attention in recent years. Traditionally, communication networks and sensing systems such as radar were developed independently because their objectives were different. Communication systems mainly focused on reliable data transmission between devices, while sensing systems were designed to detect objects and measure environmental parameters such as distance, velocity and direction. However, with the rapid development of modern wireless technologies and the increasing demand for intelligent services, the separation of these two systems is becoming less practical. As a result, Integrated Sensing and Communication (ISAC) has emerged as a promising solution that can support both functionalities simultaneously.

One of the major motivations for ISAC is the **growing scarcity of wireless spectrum**. The number of connected devices has increased dramatically due to smartphones, Internet of Things (IoT) devices, autonomous vehicles and various wireless services. Because of this rapid growth, wireless spectrum resources are becoming highly congested. At the same time, radar systems used for sensing applications also operate in frequency bands that are close to those used for communication. This leads to competition between communication systems and radar systems for spectrum allocation. By integrating sensing and communication functions into a single framework, the same spectrum resources can be shared more efficiently. This improves spectrum utilization and reduces the need for allocating separate frequency bands for different systems.

Another important motivation is the **increasing demand for intelligent and environment-aware applications**. Many emerging technologies require both reliable communication and accurate sensing capabilities at the same time. For example, autonomous vehicles need to communicate with other vehicles, roadside infrastructure and control systems while also sensing nearby objects such as pedestrians, other vehicles and obstacles. Similarly, smart transportation systems rely on communication networks to exchange information between vehicles and traffic management systems, but they also require sensing capabilities to monitor traffic conditions and detect incidents. If communication and sensing functions are implemented using separate systems, the overall infrastructure becomes more complicated and expensive. ISAC offers a more efficient solution by enabling both functionalities through a single system.

The development of **advanced signal processing and wireless hardware technologies** has also made ISAC more feasible than before. Modern communication systems already use sophisticated techniques such as Orthogonal Frequency Division Multiplexing (OFDM), multiple-input multiple-output (MIMO) antennas, beamforming and adaptive modulation schemes. Interestingly, many of these techniques are also useful for sensing operations. For example, beamforming can be used to direct wireless signals toward specific targets, which improves both communication quality and sensing accuracy. Similarly, MIMO antenna arrays can estimate the direction of incoming signals, which is useful for object localization and tracking. Because these technologies are already available in modern communication systems, integrating sensing capabilities into them does not require completely new hardware.

Another key motivation behind ISAC is **infrastructure sharing and cost reduction**. In conventional approaches, communication networks and radar sensing systems require separate infrastructure, including transmitters, receivers, antennas and signal processing units. Deploying and maintaining two independent systems increases both capital expenditure and operational cost. In contrast, ISAC systems allow a single wireless infrastructure to perform both communication and sensing tasks. For example, a base station in a cellular network can transmit signals to user devices while also using the reflected signals to sense nearby objects or monitor environmental changes. This shared infrastructure approach reduces deployment cost, saves energy and simplifies network management.

ISAC also supports the vision of **future wireless networks such as 6G**, where communication systems are expected to provide not only connectivity but also situational awareness. Future networks may act as distributed sensing platforms that can monitor traffic conditions, detect security threats and assist in navigation or automation tasks. By integrating sensing with communication, wireless networks can become more intelligent and capable of supporting advanced applications in smart cities, healthcare, robotics and industrial automation.

Furthermore, ISAC can improve **system performance and operational efficiency**. In many cases, communication signals naturally interact with the environment through reflection, scattering and diffraction. These interactions contain useful information about objects and surroundings. Traditional communication systems usually treat these reflections as interference or noise. However, ISAC systems attempt to exploit this information for sensing purposes. By analyzing reflected communication signals, the system can estimate environmental parameters without transmitting additional sensing signals. This dual use of signals increases overall system efficiency.

Finally, ISAC is motivated by the need for **low-latency and real-time operation** in modern applications. Many applications such as autonomous driving, drone navigation and industrial automation require immediate responses based on both communication data and sensing information. If sensing and communication are handled by separate systems, additional delays may occur due to data exchange between different platforms. Integrated systems can perform both tasks simultaneously, which reduces latency and improves real-time decision making.

BASIC CONCEPT OF INTEGRATED SENSING AND COMMUNICATION (ISAC)

Integrated Sensing and Communication (ISAC) is a new wireless communication paradigm in which the same wireless signals are used for both data transmission and environmental sensing. In conventional wireless systems, communication networks and sensing systems such as radar operate independently with separate hardware, spectrum and signal processing mechanisms.

However, ISAC combines these functionalities into a single framework, allowing wireless devices to communicate with each other while simultaneously observing and analyzing the surrounding environment.

The fundamental concept of ISAC is based on the idea that wireless signals naturally interact with objects in the environment through reflection, scattering and diffraction. These

Journal of Wireless Communication, Network and Mobile Engineering Technology
Volume 11, Issue 1, January-April 2026
ISSN: 3049-3137 (Online)

interactions contain valuable information about the objects around the transmitter and receiver.

Instead of treating these reflections as interference or noise, ISAC systems attempt to utilize them for sensing purposes. As a result, the transmitted signal serves a dual purpose: delivering communication data and collecting sensing information.

In a typical ISAC scenario, a base station or wireless device transmits a signal that contains encoded digital information. This signal propagates through the wireless channel and reaches the intended communication receiver. At the same time, part of the transmitted signal is reflected by objects such as buildings, vehicles, pedestrians or other obstacles present in the environment. These reflected signals travel back toward the transmitter or toward other sensing receivers.

By processing these reflected signals, the system can extract information about the environment. The analysis of these reflections enables the detection of objects, estimation of their position, and monitoring of their movement. This sensing capability is similar to the operation of radar systems, but in ISAC it is achieved using the same signals that are already used for communication.

Several physical parameters of the reflected signal can be measured to obtain sensing information. One important parameter is **time delay**, which represents the time taken by the transmitted signal to travel to an object and return to the receiver. By measuring this delay, the system can estimate the distance between the transmitter and the object. This principle is widely used in radar and ranging systems.

Another important parameter is the **Doppler shift**, which occurs when there is relative motion between the transmitter, object and receiver. If an object is moving toward the transmitter, the frequency of the reflected signal slightly increases; if the object moves away, the frequency decreases. By measuring this frequency change, the system can estimate the velocity of the object.

The **angle of arrival** or **direction of the reflected signal** is also an important sensing parameter. With advanced antenna arrays such as multiple-input multiple-output (MIMO) systems, the direction from which the reflected signal arrives can be estimated. This helps determine the position and orientation of objects within the environment.

Signal strength or amplitude variations of the received signals can also provide useful information about object characteristics such as size, material and distance. By combining these parameters, ISAC systems can perform tasks like object detection, localization, tracking and environmental mapping.

At the same time, the communication functionality of ISAC systems operates using conventional wireless communication techniques. Digital data is encoded into the transmitted waveform using modulation schemes such as Quadrature Amplitude Modulation (QAM), Phase Shift Keying (PSK) or Orthogonal Frequency Division Multiplexing (OFDM). The communication receiver processes the received signal and decodes the transmitted information using standard demodulation and decoding algorithms.

Because the same waveform supports both functions, the design of the transmitted signal becomes very important. The waveform must provide reliable data transmission while also allowing accurate sensing measurements. For example, communication systems usually aim to maximize data rate and spectral efficiency, whereas sensing systems require signals with good resolution and detection capability. These requirements may sometimes conflict with each other.

Therefore, one of the main challenges in ISAC design is **waveform optimization**. Researchers are working on developing signal structures that can efficiently support both sensing and communication objectives. Some approaches involve modifying existing communication waveforms to include sensing capabilities, while others focus on designing entirely new dual-function waveforms.

Another important component of ISAC systems is **signal processing**. The receiver must be able to separate communication data from sensing information even though both originate from the same transmitted signal. Advanced signal processing techniques are required to estimate object parameters from the reflected signals while also ensuring accurate data decoding.

Journal of Wireless Communication, Network and Mobile Engineering Technology
Volume 11, Issue 1, January-April 2026
ISSN: 3049-3137 (Online)

Beamforming techniques also play an important role in ISAC systems. With directional beamforming, the transmitted signal can be focused toward a specific user or target area. This improves communication quality while also enhancing sensing accuracy by concentrating signal energy in desired directions.

In addition, modern ISAC systems may use distributed sensing, where multiple base stations or devices cooperate to sense the environment. By sharing sensing information, the network can obtain a more accurate understanding of the surroundings and improve overall system performance.

ISAC SYSTEM ARCHITECTURE

The architecture of an Integrated Sensing and Communication (ISAC) system can vary depending on the specific application, network structure and deployment environment. However, most ISAC systems share several common components such as transmitters, receivers, signal processing units, sensing modules and control units. These components work together to enable simultaneous communication and sensing operations using the same wireless signals and hardware infrastructure.

In many proposed ISAC architectures, the **base station or access point acts as both a communication node and a sensing unit**. The base station transmits wireless signals to user devices for communication purposes. At the same time, it observes and processes the signals that are reflected from objects in the environment. By analyzing these reflected signals, the base station can obtain information about nearby objects, such as their position, speed and movement.

A typical ISAC architecture includes several functional blocks which perform different tasks in the integrated system. These blocks are described below.

1. Transmitter Module

The transmitter module is responsible for generating and transmitting wireless signals that carry communication data. In ISAC systems, the transmitted waveform is designed in such a way that it can also support sensing functions.

Digital information from users or network applications is first processed and encoded using modulation techniques such as Quadrature Amplitude Modulation (QAM), Phase Shift Keying (PSK) or Orthogonal Frequency Division Multiplexing (OFDM). After modulation, the signal is amplified and transmitted through antennas into the wireless channel.

Because ISAC systems must support both sensing and communication, the transmitted waveform often needs special design considerations. The waveform should allow accurate detection of reflected signals while still maintaining high communication performance.

2. Antenna Array and Beamforming Unit

Modern ISAC systems often use **antenna arrays** such as Multiple-Input Multiple-Output (MIMO) systems. These arrays consist of multiple antennas that can transmit and receive signals simultaneously.

Beamforming techniques are applied to control the direction of the transmitted signals. By adjusting the phase and amplitude of signals across different antennas, the system can steer the signal energy toward a specific direction. This improves communication quality for intended users and also enhances sensing performance by focusing energy on specific targets.

Directional beamforming also helps reduce interference and improve spatial resolution for sensing tasks.

3. Communication Receiver

The communication receiver processes signals that are received from user devices. Its primary function is to recover the transmitted digital information.

The receiver performs several operations such as signal amplification, filtering, demodulation and decoding. Advanced algorithms are used to reduce noise and interference so that the original communication data can be accurately reconstructed.

In ISAC systems, the receiver must also operate alongside sensing operations without causing interference between the two processes.

4. Sensing Receiver and Radar Processing Unit

The sensing receiver is responsible for capturing signals that are reflected from objects in the surrounding environment. These reflected signals are usually weaker than the direct communication signals, so sensitive detection techniques are required.

Once the reflected signals are received, they are processed by a radar or sensing processing unit. This unit analyzes different characteristics of the signals such as time delay, frequency shift and signal strength.

From these measurements, the system can estimate parameters including:

- Distance between the transmitter and objects
- Relative velocity of moving objects
- Direction or angle of objects
- Movement patterns over time

This information allows the system to detect and track objects within the environment.

5. Signal Processing and Data Fusion Unit

The signal-processing unit is one of the most important components of an ISAC system. It combines information obtained from communication signals and sensing reflections.

This unit performs advanced processing tasks such as channel estimation, interference mitigation, parameter estimation and object detection. In some systems, machine learning algorithms may also be used to analyze sensing data and improve system performance.

Data fusion techniques may also be applied when multiple sensors or base stations are involved. By combining sensing data from different sources, the system can achieve more accurate environmental awareness.

6. Control and Resource Management Module

The control module manages system resources such as power allocation, spectrum usage and beamforming configuration. Since communication and sensing operations share the same resources, efficient coordination is required to maintain balanced performance.

For example, the system may dynamically adjust transmission power or beam direction depending on the communication requirements and sensing tasks. Intelligent resource management ensures that neither sensing nor communication performance is significantly degraded.

7. Example ISAC Operational Flow

The basic operation of an ISAC system can be described through the following steps:

1. The base station generates a communication signal containing digital information.
2. The signal is transmitted through antennas toward user devices.
3. User devices receive the signal and decode the communication data.
4. Some portion of the transmitted signal reflects from objects in the environment.
5. The reflected signals are received by the sensing receiver.
6. Signal processing algorithms analyze the reflections to estimate object parameters such as distance and velocity.

Through this integrated process, a single wireless signal supports both communication and sensing tasks simultaneously.

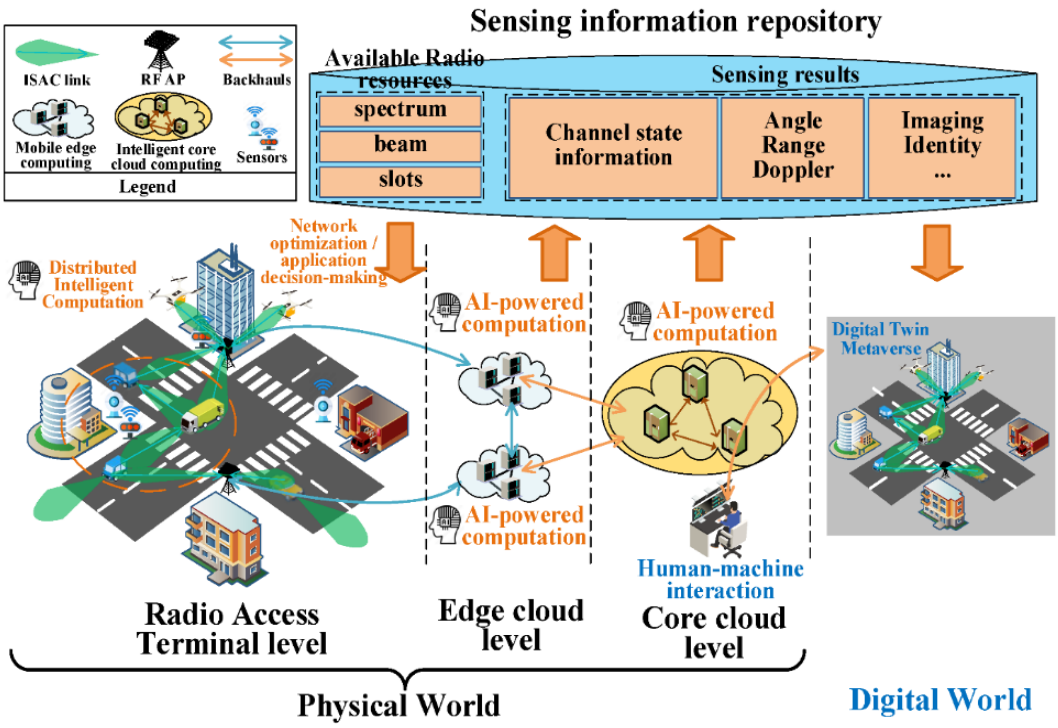

Figure 1: Basic architecture of Integrated Sensing and Communication system

DESIGN APPROACHES FOR ISAC

Different design approaches have been proposed for implementing ISAC systems.

1. Radar-Centric Design

In radar-centric design, the system is primarily designed as a radar system and communication capability is added later. The radar waveform is slightly modified to embed communication data.

This approach ensures strong sensing performance but communication capacity may be limited.

2. Communication-Centric Design

In communication-centric design, the system is mainly optimized for data transmission. Sensing functionality is added by analyzing the communication signals and their reflections.

This approach allows high communication performance but sensing accuracy may not be optimal.

3. Joint Design Approach

The joint design approach optimizes the waveform and system parameters for both sensing and communication simultaneously. This approach tries to achieve a balance between communication throughput and sensing accuracy.

Joint design is considered the most promising approach for future ISAC systems.

ENABLING TECHNOLOGIES FOR ISAC

Several modern wireless technologies enable the implementation of Integrated Sensing and Communication systems.

1. Millimeter-Wave Communication

Millimeter-wave (mmWave) communication operates at frequencies between 30 GHz and 300 GHz. These high frequencies provide large bandwidth which allows very high data rates.

The short wavelength of mmWave signals also enables precise sensing and object detection. Therefore mmWave technology is highly suitable for ISAC systems.

2. Massive MIMO

Massive Multiple-Input Multiple-Output (MIMO) technology uses a large number of antennas at the transmitter and receiver. This allows highly directional beamforming which improves both communication and sensing performance.

Massive MIMO can also estimate the direction of incoming signals which is useful for object localization.

3. Artificial Intelligence and Machine Learning

Machine learning algorithms can improve the performance of ISAC systems by optimizing waveform design, beamforming and resource allocation.

AI techniques can also analyze sensing data to detect patterns and improve object recognition.

4. Edge Computing

Edge computing allows data processing to be performed closer to the network edge rather than in centralized cloud servers. This reduces latency and enables real-time sensing and communication operations.

APPLICATIONS OF ISAC

Integrated Sensing and Communication has many potential applications in future wireless networks.

1. Autonomous Vehicles

Autonomous vehicles require accurate sensing to detect obstacles and communicate with other vehicles. ISAC can provide both functionalities using the same wireless infrastructure.

2. Smart Cities

In smart cities, ISAC systems can monitor traffic conditions, detect accidents and provide communication services to connected devices.

3. Drone Networks

Unmanned aerial vehicles (UAVs) can use ISAC to communicate with control stations while sensing nearby obstacles and terrain.

4. Industrial Automation

Factories and industrial plants can use ISAC for monitoring equipment, detecting object movement and enabling reliable communication between machines.

Table 1: Comparison between Traditional Systems and ISAC

Feature	Traditional Communication	Radar Sensing System	ISAC System
Primary Function	Data transmission	Object detection	Both sensing and communication
Spectrum Usage	Dedicated bands	Separate radar bands	Shared spectrum
Hardware Infrastructure	Communication hardware	Radar hardware	Shared hardware
Efficiency	Moderate	Moderate	High
Deployment Cost	Medium	High	Lower due to integration

CHALLENGES OF ISAC SYSTEMS

Although ISAC offers many advantages, several technical challenges still exist.

One major challenge is waveform design. The transmitted waveform must satisfy both communication and sensing requirements which may conflict with each other.

Another challenge is interference management. In integrated systems, sensing signals and communication signals may interfere with each other.

Hardware complexity is also a concern. Implementing high-performance ISAC systems requires advanced antennas, signal processors and synchronization mechanisms.
Security and privacy issues must also be considered. Since ISAC systems can sense the environment, there is a risk of unauthorized monitoring.

FUTURE RESEARCH DIRECTIONS

Research on Integrated Sensing and Communication is still in early stages and many topics require further investigation.

Future research may focus on advanced waveform design methods that optimize both communication and sensing performance. Researchers are also exploring the use of terahertz frequencies for high-resolution sensing and ultra-high data rates.

Another important research direction is the use of AI-based algorithms for dynamic resource allocation and intelligent sensing.

Standardization and practical deployment strategies will also be important for the successful adoption of ISAC technology in 6G networks.

CONCLUSION

Integrated Sensing and Communication is emerging as an important technology for next generation wireless networks. By combining communication and sensing functionalities into a single system, ISAC can significantly improve spectrum efficiency, reduce infrastructure cost and enable many new applications.

This paper reviewed the basic concepts, system architectures, design approaches and enabling technologies of ISAC systems. Several potential applications including autonomous vehicles, smart cities and industrial automation were discussed. The paper also highlighted major technical challenges such as waveform design, interference management and hardware complexity.

Although ISAC technology is still under active research, it has strong potential to become a key component of future 6G wireless networks. With continued research and technological advancements, practical ISAC systems may soon be deployed in real world environments.

REFERENCES

1. Liu F., Masouros C., Petropulu A., “Integrated Sensing and Communications: Toward Dual-Functional Wireless Networks”, IEEE Communications Magazine, 2020.

2. Zhang J., Renzo M., Debbah M., “Joint Radar and Communication Systems: A Survey”, IEEE Transactions on Communications, 2021.
3. Kumari P., Choi J., González-Prelcic N., Heath R., “IEEE 802.11ad-Based Radar: An Approach to Joint Vehicular Communication and Radar Sensing”, IEEE Transactions on Vehicular Technology, 2018.
4. Hassanien A., Amin M., “Dual-Function Radar Communication Systems: Information Embedding Using Sidelobe Control”, IEEE Transactions on Aerospace and Electronic Systems, 2016.
5. Feng Z., Fang Z., Wei Z., Chen X., “Joint Radar and Communication: A Survey”, China Communications, 2020.
6. Wang B., Liu Y., Chen H., “Millimeter Wave Communication for 5G and Beyond”, IEEE Wireless Communications, 2019.
7. Chen X., Zhang H., “Integrated Sensing and Communication for 6G Wireless Networks”, IEEE Network, 2021.
8. Liu Y., Sun S., “Massive MIMO Enabled Integrated Sensing and Communication”, IEEE Communications Letters, 2022.
9. Zhou S., Wang Y., “AI Assisted Integrated Sensing and Communication Systems”, IEEE Access, 2022.
10. Li K., Zhang L., “Future Research Challenges in Integrated Sensing and Communication”, International Journal of Wireless Networks, 2023.

Cite as:

Vaishnavi Shinde, Yashshree Jadhav (2026). Integrated Sensing and Communication (ISAC). Journal of Wireless Communication, Network and Mobile Engineering Technology, 11(1), 17-32.

https://doi.org/10.5281/zenodo.19639470

