

Satellite Communication Technologies for Disaster Management: A Review of Recent Advances and Applications

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Abstract

Natural disasters such as earthquakes, floods, cyclones, landslides, and wildfires often damage conventional communication infrastructure, making coordination among emergency response teams difficult. Satellite communication has emerged as a reliable solution due to its wide coverage, rapid deployment, and ability to operate independently of terrestrial networks. This review paper presents an overview of recent advancements in satellite communication technologies and their applications in disaster management. The study examines different satellite systems, including Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) satellites, and discusses their roles in emergency communication networks. In addition, the paper reviews the integration of satellite communication with unmanned aerial vehicles (UAVs), remote sensing technologies, and next-generation wireless networks to improve disaster monitoring, real-time information sharing, and rescue operations. A comparative analysis of recent research highlights the strengths, limitations, and practical applications of these technologies. Finally, the paper discusses future directions, including space-air-ground integrated communication networks and intelligent disaster response systems. This review provides a concise understanding of the role of satellite communication in enhancing disaster preparedness, response, and recovery.

Index Terms: Satellite Communication ,Disaster Management, Emergency Communication, Unmanned Aerial, Vehicle (UAV), Emergency

Response, LEO Satellite, GEO Satellite, Disaster Monitoring, Communication Networks.

I. INTRODUCTION

Natural disasters such as earthquakes, floods, cyclones, landslides, wildfires, and tsunamis have become increasingly frequent and severe, causing significant loss of life, property, and critical infrastructure worldwide. One of the most serious consequences of these events is the disruption of communication networks, which affects the timely coordination of rescue operations, emergency medical services, and disaster management authorities. Conventional terrestrial communication systems, including cellular networks, optical fiber links, and telephone networks, often become overloaded or are physically damaged during major disasters, resulting in communication failures that delay emergency response.

Satellite communication has emerged as one of the most reliable technologies for maintaining connectivity during disaster situations. Unlike terrestrial communication systems, satellite networks are independent of ground infrastructure and can provide wide-area coverage even in remote or severely affected regions. These characteristics make satellite communication an essential component of modern disaster management systems. Satellite-based communication supports emergency voice communication, data transmission, real-time video streaming, navigation, and coordination among rescue teams, thereby improving the efficiency of disaster response and recovery operations.

Recent technological developments have significantly enhanced the capabilities of satellite communication systems. The deployment of Low Earth Orbit (LEO) satellite constellations has reduced communication latency while increasing data transmission speed. Similarly, advances in Geostationary Earth Orbit (GEO) and Medium Earth Orbit (MEO) satellite systems have improved global coverage, reliability, and service availability. In addition, the integration of satellite communication with emerging technologies such as unmanned aerial vehicles (UAVs), remote sensing, Internet of Things (IoT), wireless mesh networks, and fifth-generation (5G) communication has created more efficient emergency communication networks capable of providing real-time situational awareness and rapid disaster assessment.

Several studies have highlighted different aspects of satellite communication in disaster management. The communication failures experienced during the Great East Japan Earthquake demonstrated the vulnerability of conventional communication systems and emphasized the need for resilient emergency communication networks. Recent review studies have further explored the role of satellite communication, cellular communication, wireless ad hoc networks, and integrated emergency communication architectures. Moreover, recent research has demonstrated the practical implementation of UAV-based aerial remote sensing platforms combined with real-time satellite communication, enabling rapid acquisition and transmission of disaster information to emergency response centers.

This review paper provides a concise overview of satellite communication technologies used in disaster management and emergency response. It discusses different satellite systems, their integration with modern emergency communication networks, and their applications in disaster monitoring and rescue operations. Furthermore, the paper presents a comparative

analysis of recent research, identifies current challenges, and highlights future directions for developing reliable and intelligent disaster communication systems. The objective of this review is to provide students and researchers with a clear understanding of how satellite communication contributes to improving disaster preparedness, response, and recovery.

DISASTER COMMUNICATION CHALLENGES

Effective communication is one of the most critical requirements during disaster management, as it enables coordination among emergency responders, government agencies, healthcare services, and affected communities. However, natural disasters frequently damage or overload conventional communication infrastructure, making the exchange of timely information extremely difficult. Communication failures during the initial hours of a disaster can delay rescue operations, reduce situational awareness, and increase the risk to both victims and emergency personnel.

One of the primary challenges is the **failure of terrestrial communication infrastructure**. Earthquakes, floods, cyclones, and landslides can damage cellular towers, optical fiber cables, power supply systems, and telephone networks. Even when physical infrastructure remains intact, communication networks often become congested because thousands of users attempt to access the network simultaneously. This network congestion significantly reduces the availability of voice and data services, making emergency communication unreliable.

Another major challenge is the **limited accessibility of remote and disaster-affected regions**. Rescue teams often operate in mountainous areas, forests, islands, or flood-affected locations where terrestrial communication networks are either unavailable or severely damaged. The lack of reliable communication restricts the transmission of

real-time information, including the location of victims, weather conditions, and resource requirements. Consequently, decision-makers may not receive accurate situational updates, affecting the efficiency of rescue and relief operations.

Disaster management also requires the **rapid transmission of high-quality data**, such as satellite images, aerial photographs, videos, and sensor information. Conventional communication systems are often unable to provide the required bandwidth or reliability under emergency conditions. Recent disaster response operations increasingly depend on unmanned aerial vehicles (UAVs), remote sensing platforms, and Internet of Things (IoT) devices, all of which generate large volumes of data that must be transmitted securely and with minimal delay.

Interoperability among different communication systems is another significant challenge. Emergency response organizations frequently use different communication technologies, including public cellular networks, private radio systems, satellite communication, and wireless mesh networks. The absence of a unified communication platform makes information sharing difficult and may delay coordination between multiple agencies involved in disaster response.

To address these challenges, modern disaster management systems are increasingly adopting **satellite communication** as a reliable alternative. Satellite networks operate independently of terrestrial infrastructure, provide extensive geographic coverage, and support communication even when ground-based networks fail. Furthermore, the integration of satellite communication with UAVs, remote sensing technologies, wireless ad hoc networks, and next-generation 5G/6G communication systems has significantly improved emergency communication capabilities. These technologies enable rapid deployment, real-time information exchange, and effective coordination among rescue

teams, thereby enhancing disaster preparedness, response, and recovery.

Challenge	Impact on Disaster Response	Possible Solution
Damage to communication infrastructure	Loss of voice and data connectivity	Satellite communication
Network congestion	Delayed emergency communication	Priority emergency communication protocols
Remote and inaccessible locations	Limited communication coverage	LEO/GEO satellite networks and UAVs
Large-volume data transmission	Slow image and video transfer	High-bandwidth satellite links
Interoperability between agencies	Poor coordination and information sharing	Integrated emergency communication networks

Figures

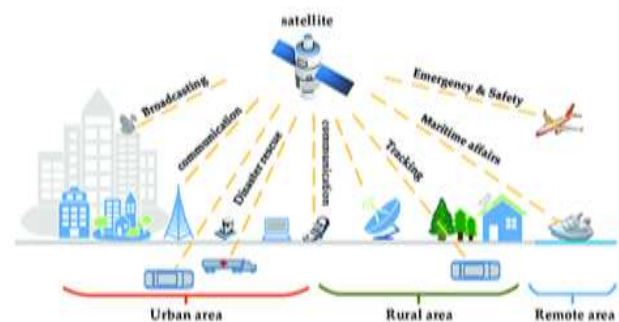


FIGURE 1. ROLE OF SATELLITE COMMUNICATION IN DISASTER MANAGEMENT

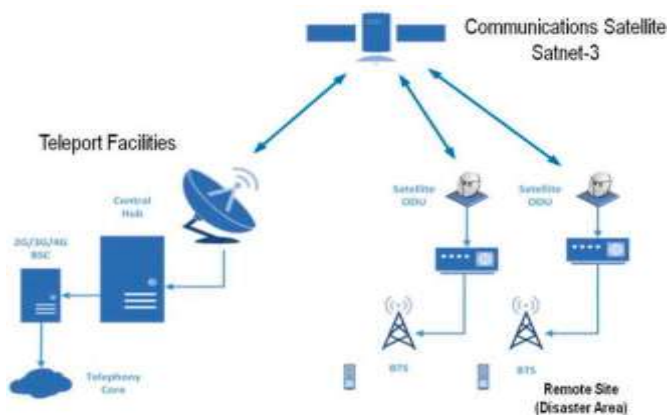


Figure 2. Communication Challenges During Disaster Response

SATELLITE COMMUNICATION TECHNOLOGIES

Satellite communication is one of the most reliable technologies for maintaining communication during natural and man-made disasters. Unlike terrestrial communication systems, satellite networks do not depend on ground-based infrastructure such as cellular towers or optical fiber cables. Therefore, they continue to provide communication services even when conventional networks are damaged or unavailable. Satellite communication plays an essential role in disaster management by enabling emergency voice communication, data transmission, navigation, remote sensing, and coordination among rescue teams.

Satellite communication systems consist of three main components: the **space segment**, which includes communication satellites; the **ground segment**, comprising earth stations and control centers; and the **user segment**, which includes portable satellite phones, emergency communication terminals, mobile command vehicles, and UAV-based communication devices. During disaster response, information collected from affected areas is transmitted through satellites to emergency operation centers, allowing authorities to monitor the situation and coordinate rescue activities efficiently.

Based on orbital altitude, communication satellites are classified into **Geostationary Earth Orbit**

(GEO), **Medium Earth Orbit (MEO)**, and **Low Earth Orbit (LEO)** satellites. Each system offers different advantages depending on the communication requirements.

Geostationary Earth Orbit (GEO) satellites operate at an altitude of approximately **35,786 km** above the Earth's equator. Since they rotate at the same speed as the Earth, they appear stationary relative to a fixed location. GEO satellites provide extensive geographical coverage, making them suitable for weather forecasting, television broadcasting, emergency communication, and disaster monitoring. However, the long communication distance introduces higher transmission delay, which limits their performance in real-time interactive applications.

Medium Earth Orbit (MEO) satellites are positioned between **2,000 km and 20,000 km** above the Earth. They offer lower latency than GEO satellites while providing wider coverage than LEO satellites. MEO systems are widely used for global navigation and positioning services, including disaster location tracking and emergency logistics planning. They provide a balanced solution in terms of coverage, communication delay, and operational cost.

Low Earth Orbit (LEO) satellites operate at altitudes ranging from approximately **500 km to 2,000 km**. Due to their close proximity to the Earth, LEO satellites provide high data rates, low communication latency, and improved image transmission capabilities. Modern LEO satellite constellations support broadband internet, real-time video transmission, and rapid disaster information exchange. These characteristics make LEO satellites highly suitable for emergency communication, UAV connectivity, and remote sensing applications. However, because each satellite covers a relatively small area, multiple satellites are required to achieve continuous global coverage.

Recent advances in satellite communication have significantly improved disaster response capabilities. The integration of satellite communication with **remote sensing**, **unmanned aerial vehicles (UAVs)**, **Internet of Things (IoT)** devices, and **5G communication networks** enables real-time monitoring, rapid damage assessment, and faster decision-making during emergencies. These integrated systems enhance communication reliability, improve coordination among rescue teams, and support efficient disaster preparedness, response, and recovery.

Although satellite communication provides several advantages, including global coverage, infrastructure independence, and high reliability, it also faces challenges such as high deployment costs, weather-related signal attenuation at higher frequencies, and limited bandwidth in some systems. Nevertheless, continuous technological advancements are making satellite communication increasingly affordable and efficient for disaster management applications.

Parameter	GEO	MEO	LEO
Altitude	~35,786 km	2,000–20,000 km	500–2,000 km
Coverage	Very High	Medium	Low (per satellite)
Communication Delay	High	Medium	Low
Data Transmission Speed	Moderate	High	Very High
Number of Satellites Required	Few	Moderate	Large Constellation
Major Applications	Broadcasting, Weather Monitoring	Navigation, Positioning	Broadband Internet, Disaster Communication



Figure 3. Satellite Communication Architecture for Disaster Management

Applications of Satellite Communication in Disaster Management

Satellite communication has become an essential component of modern disaster management because it provides reliable communication and real-time information even when conventional communication infrastructure is damaged. By integrating satellite networks with remote sensing, unmanned aerial vehicles (UAVs), and emergency communication systems, disaster response has become faster, more accurate, and better coordinated. The major applications of satellite communication in disaster management are discussed below.

- *Emergency Communication*

One of the primary applications of satellite communication is establishing emergency communication immediately after a disaster. Earthquakes, floods, cyclones, and wildfires often destroy cellular towers, telephone lines, and optical fiber networks, making terrestrial communication unavailable. Satellite communication operates independently of ground infrastructure and enables emergency responders, government agencies, and medical teams to maintain continuous voice, video, and data communication. This ensures effective coordination during search-and-rescue operations and allows emergency information to be shared without interruption.

- *Disaster Monitoring and Remote Sensing*

Satellite-based remote sensing plays a vital role in monitoring natural disasters before, during, and after their occurrence. Optical and radar sensors mounted on satellites capture high-resolution images of affected regions, allowing authorities to assess flood extent, earthquake damage, wildfire spread, and landslide locations. These images support rapid damage assessment and help emergency managers identify the areas that require immediate assistance. Continuous satellite observation also improves disaster preparedness by monitoring environmental changes and providing early warning information.

- *UAV-Assisted Disaster Assessment*

Recent advances have enabled the integration of satellite communication with unmanned aerial vehicles (UAVs). UAVs equipped with high-resolution cameras can collect detailed images and videos of disaster-affected areas where ground access is difficult or dangerous. Satellite communication enables these data to be transmitted in real time to emergency operation centers, allowing rescue teams to monitor disaster conditions and make quick decisions. This combination improves situational awareness while reducing risks to emergency personnel.

- *Search and Rescue Operations*

Satellite communication significantly enhances search-and-rescue activities by supporting real-time coordination among multiple emergency response teams. Rescue vehicles, portable satellite terminals, GPS devices, and mobile command centers can exchange location information, victim status, and operational updates even in remote or isolated regions. Accurate positioning and continuous communication improve the efficiency of rescue missions and reduce response time, particularly during large-scale disasters.

- *Integrated Disaster Response Systems*

Modern disaster management increasingly relies on integrated communication systems that combine satellite communication with wireless mesh

networks, Internet of Things (IoT) sensors, cellular communication, and next-generation 5G technologies. These hybrid systems enable continuous monitoring of environmental conditions, automatic transmission of sensor data, and efficient coordination between multiple agencies. Such integrated networks provide greater communication reliability, wider coverage, and improved disaster response compared with standalone communication systems.

Overall, satellite communication has transformed disaster management by enabling reliable connectivity, rapid information sharing, and effective coordination throughout all phases of disaster response. Continuous improvements in satellite technology, remote sensing, and UAV communication are expected to further strengthen emergency communication capabilities and enhance disaster resilience in the future.

Table 3. Applications of Satellite Communication in Disaster Management

Application	Role of Satellite Communication	Benefits
Emergency Communication	Provides communication when terrestrial networks fail	Reliable connectivity
Remote Sensing	Captures real-time disaster images	Rapid damage assessment
UAV-Based Monitoring	Transfers aerial images and videos in real time	Improved situational awareness
Search and Rescue	Supports GPS tracking and team coordination	Faster rescue operations
Early Warning Systems	Disseminates alerts and weather information	Reduced disaster impact
Integrated Emergency	Connects satellite, IoT, UAV, and 5G	Better coordination

Application	Role of Satellite Communication	Benefits
Networks	systems	and coverage

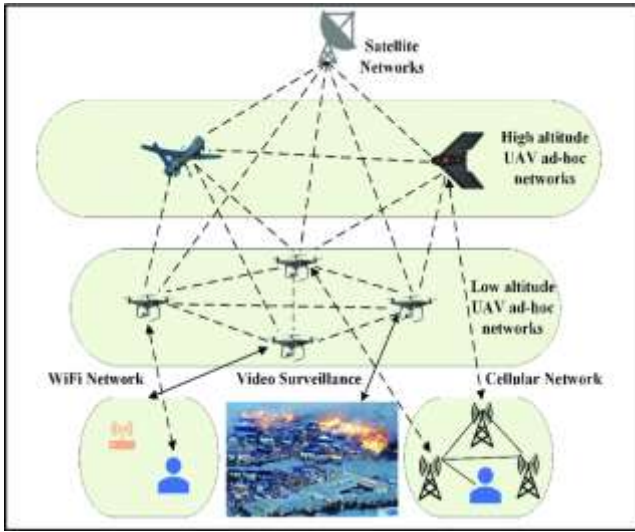


Figure 4. Major applications of satellite communication in disaster management.

FUTURE SCOPE

Satellite communication continues to evolve rapidly and is expected to play an increasingly important role in disaster management. Future research should focus on developing **integrated communication systems** that combine satellite networks with fifth-generation (5G) and sixth-generation (6G) wireless technologies, Internet of Things (IoT) devices, unmanned aerial vehicles (UAVs), and artificial intelligence (AI). Such integrated systems can provide continuous connectivity, intelligent decision support, and real-time information sharing during emergency situations.

The rapid deployment of **Low Earth Orbit (LEO) satellite constellations** is expected to improve emergency communication by providing lower latency, higher data transmission rates, and wider global coverage. These systems will support real-time video transmission, remote sensing, and broadband communication even in remote and disaster-affected areas where terrestrial networks are unavailable.

Another promising direction is the application of **Artificial Intelligence (AI)** and **Machine Learning (ML)** for disaster prediction and communication management. AI-based systems can analyze satellite imagery, sensor data, and weather information to identify potential hazards, predict disaster impacts, and optimize resource allocation during rescue operations. Similarly, IoT-based environmental monitoring systems can continuously collect field data and automatically transmit alerts through satellite communication networks.

Future disaster management systems are also expected to adopt **space-air-ground integrated networks**, where satellites, UAVs, terrestrial communication systems, and remote sensing platforms operate as a unified communication infrastructure. Such architectures will improve network reliability, reduce communication delays, and ensure uninterrupted connectivity during large-scale emergencies.

Although satellite communication technology has advanced significantly, challenges such as deployment cost, spectrum availability, cyber security, and communication reliability under extreme environmental conditions still require further research. Addressing these challenges will make future emergency communication systems more efficient, secure, and accessible.

COMPARATIVE ANALYSIS OF RECENT STUDIES

Recent research demonstrates that satellite communication has become an indispensable technology for disaster management. The four reviewed studies address different aspects of emergency communication, ranging from communication failures during disasters to advanced satellite-enabled emergency response systems. Although all the studies focus on improving disaster communication, they differ in their objectives, methodologies, and application areas.

The study on the **Great East Japan Earthquake (2014)** primarily investigates the communication problems experienced during a large-scale disaster. It highlights the vulnerability of terrestrial communication networks and emphasizes the importance of resilient communication systems during emergency situations. However, the study mainly analyzes communication failures and provides limited discussion on modern communication technologies.

The **Electronics (2022)** review presents a comprehensive overview of various emergency communication technologies, including satellite communication, wireless mesh networks, IoT, UAVs, and 5G systems. It demonstrates that combining multiple communication technologies can significantly improve disaster response. However, the study remains largely conceptual and does not evaluate practical system performance.

The **Remote Sensing (2023)** review extends the discussion by examining different emergency communication network architectures, including GEO, MEO, and LEO satellite systems, cellular communication, and integrated space–air–ground networks. The paper highlights the advantages of hybrid communication systems but provides limited implementation-based validation.

The most recent study, **Remote Sensing (2024)**, focuses on the practical implementation of an aerial remote sensing platform integrated with real-time satellite communication. It demonstrates how UAVs equipped with satellite communication can rapidly collect and transmit disaster information to emergency operation centers. This work illustrates the growing trend toward intelligent and real-time disaster response systems.

Overall, the reviewed literature indicates a clear evolution in disaster communication research. Earlier studies focused on identifying communication failures, while recent research emphasizes integrated satellite communication, UAV-assisted monitoring, and remote sensing technologies for rapid disaster response. Future

disaster management systems are expected to combine satellite communication with artificial intelligence, IoT, and next-generation 6G networks to achieve faster, more reliable, and more resilient emergency communication.

Reference	Year	Main Focus	Technology Used	Key Contribution	Limitation
Paper 1	2014	Communication failures during the Great East Japan Earthquake	Satellite phones, terrestrial networks	Identified major communication challenges during disasters	Focused on a single disaster event
Paper 2	2022	Review of emergency communication technologies	Satellite, IoT, UAV, Mesh Network, 5G	Comprehensive overview of modern emergency communication systems	Limited practical implementation
Paper 3	2023	Emergency communication network architectures	GEO, MEO, LEO, cellular, ad hoc networks	Reviewed integrated emergency communication networks	Limited experimental validation

Reference	Year	Main Focus	Technology Used	Key Contribution	Limitation
Paper 4	2024	UAV-based satellite communication platform	UAV, remote sensing, satellite communication	Demonstrated real-time disaster monitoring and data transmission	Application focused on a specific platform

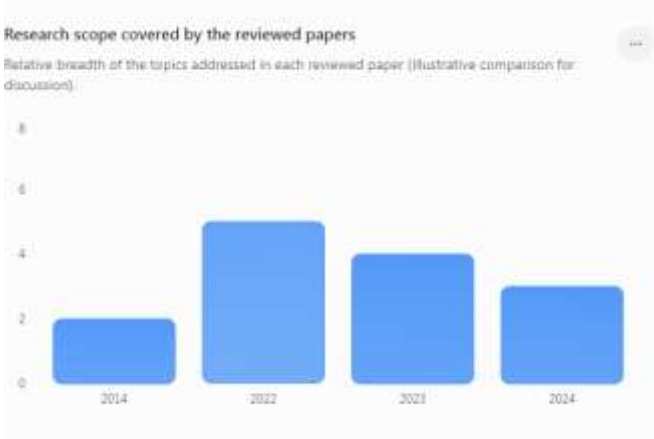


Chart 1. Comparison of the Reviewed Papers by Research Scope

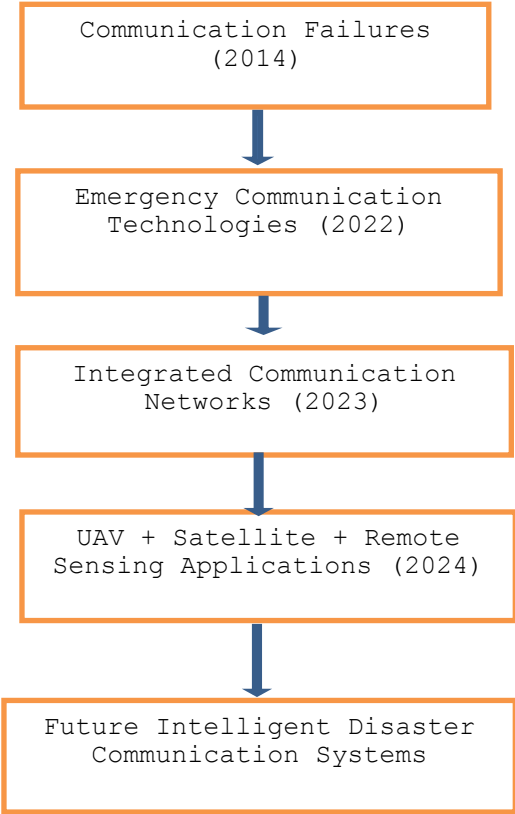


Figure 5. Evolution of Disaster Communication Research

CONCLUSION

Reliable communication is one of the most important requirements for effective disaster management. Natural disasters frequently damage terrestrial communication infrastructure, making coordination among emergency responders difficult during the critical early stages of rescue operations. Satellite communication has emerged as a dependable solution because it provides wide-area coverage, operates independently of ground infrastructure, and supports continuous communication in affected regions.

This review paper examined recent developments in satellite communication technologies for disaster management by analyzing four representative studies. The review discussed communication challenges during disasters, the characteristics of GEO, MEO, and LEO satellite systems, and the integration of satellite communication with UAVs, remote sensing, IoT, and emergency communication networks. A comparative analysis showed the evolution of disaster communication research from identifying communication failures to developing intelligent and integrated emergency communication systems.

The review indicates that hybrid communication architectures combining satellite communication with modern wireless technologies can significantly improve disaster preparedness,

response, and recovery. Advances in LEO satellite constellations, AI-assisted disaster monitoring, UAV-enabled communication, and integrated space–air–ground networks are expected to further strengthen emergency communication capabilities in the coming years.

In conclusion, satellite communication remains one of the most effective technologies for ensuring reliable connectivity during disasters. Continued technological innovation and the integration of emerging communication systems will contribute to building more resilient, efficient, and intelligent disaster management frameworks capable of supporting faster emergency response and minimizing the impact of future disasters.

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