Exploring the Construction of Technical Architecture for Emergency Broadcast Systems in the IoT Era from Application Scenarios: Post-Print

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Abstract

This paper addresses the current role of broadcast applications in China, analyzes the advantages and disadvantages of various broadcast technology modes, and based on the development status of the Internet of Things in China, analyzes the current development status of emergency broadcast technology, and explores IoT emergency broadcast technology, architecture, application scenarios, and development directions.

Full Text

Preamble

Exploring the Technical Architecture Construction of Emergency Broadcast Systems in the IoT Era from Application Scenarios

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Abstract: This paper analyzes the current role of broadcast applications in China, examines the advantages and disadvantages of various broadcast technology modes, and investigates the development status of emergency broadcast technologies in the context of China' s IoT growth. It explores IoT-based emergency broadcast technologies, architectures, application scenarios, and future development directions.

Keywords: Internet of Things; Internet; Emergency Broadcast System; 4G/5G; Emergency Broadcast Technology

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1. The Role of Emergency Broadcast in Public Emergencies

Public emergencies refer to sudden incidents that cause or may cause serious social harm, requiring emergency response measures to address natural disasters, accidental catastrophes, public health events, and social security incidents. Key characteristics include: sudden outbreak and unpredictability; rapid spread and difficulty in containment; disorderly changes and challenges in control; severe losses that are hard to estimate; and profound, lasting impacts. In response, Chinese authorities have attached great importance to the application of emergency broadcast in public emergency management, strengthening supervision and establishing strict regulations. This comprehensive management of emergency broadcast applications in public emergencies has positively impacted modern social stability, enabling timely policy dissemination, important message delivery, correct guidance of public opinion, and fulfillment of emergency broadcast' s essential functions.

For instance, on June 17, 2019, at 22:55, a 6.0-magnitude earthquake struck Changning County, Yichang City, Sichuan Province. Local authorities used emergency broadcast systems to provide citizens with 10-60 seconds of critical evacuation time, transmitting early warnings through television, loudspeakers, and multiple terminals, thereby minimizing the disaster' s impact and protecting lives and property. Similarly, during the COVID-19 pandemic in early 2020, emergency broadcast played a vital role in disseminating prevention and control information to the "last kilometer," enabling regions and cities to effectively manage the outbreak. These examples demonstrate emergency broadcast' s crucial role in public emergencies, prompting strong government support for system construction, management innovation, and regulatory development to comprehensively address such events.

2.1 Wired Analog Constant-Voltage Broadcast Technology

Wired analog constant-voltage broadcast technology amplifies audio signals and transmits them through power lines to speakers for signal distribution. The front-end consists of a constant-voltage broadcast power amplifier that processes audio sources and amplifies power, which is then transmitted via wires to the emergency broadcast system speakers. To address line transmission losses, step-up transformers convert audio signals into various constant-voltage modes (e.g., 100V, 70V, 120V) to meet transmission requirements while reducing 损耗. Front-end processing also facilitates terminal step-down conversion, expanding signal transmission distance and efficiency by converting from 4Ω to 16Ω to drive horns.

Advantages: Mature technology, simple structure, stable performance, easy maintenance, and inexpensive terminals.

Disadvantages: Poor audio quality, high distortion, small program capacity, no addressable control, outdated technology, simple functionality, poor scalability, limited transmission distance, and physical line partitioning constraints that prevent individual broadcast point control. Single lines can only transmit one program source, preventing real-time multi-source single-point transmission. The lack of a return channel prevents real-time monitoring of terminal status. These limitations make it unsuitable for county-wide applications, particularly for rescue operations, and the technology has been largely phased out.

2.2 Wired Coaxial Cable FM Broadcast Technology

Wired FM broadcast utilizes frequency-division multiplexing over cable television coaxial cables. Audio signals are modulated via FM (87MHz-108MHz) and combined with CATV signals for transmission through coaxial cable or fiber, known as FM+CATV co-cable transmission.

Advantages: Leverages existing CATV infrastructure without separate wiring, maintains CATV signal integrity, offers relatively low cost, enables multi-channel simultaneous transmission, supports intelligent addressable terminal control, and uses tree-structured cabling with minimal interference in the FM band. Appropriate carrier frequency selection can avoid interference signals.

Disadvantages: Frequency drift and noise issues, inability to implement county-town-village tri-level joint broadcasting and control according to administrative divisions, limited co-cable coverage affecting scalability, and lack of a return channel for real-time terminal monitoring. These defects limit county-wide applications, though the technology remains in use in some areas.

2.3 Wireless FM Broadcast Technology

Wireless FM broadcast transmits signals through wireless emission, modulating audio signals via FM (87MHz-108MHz) within a defined spatial range.

Advantages: Multi-channel simultaneous transmission, intelligent addressable terminal control, wider transmission bandwidth than AM signals providing better noise immunity, and the ability to implement county-town-village tri-level joint broadcasting and control by administrative divisions.

Disadvantages: Wide FM bandwidth reduces space frequency resource utilization; coverage is limited by transmitter power and geography, with obstacles significantly affecting FM signals; installation of transmission antennas at county, town, and village levels is cumbersome and reliability is difficult to guarantee; and the lack of a return channel prevents real-time terminal monitoring. These limitations restrict its application to certain regions.

2.4 Digital Television (DVB-C/DTMB) Broadcast Technology

Digital television broadcast technology operates under the coordination of broadcast system management platforms. Following standard encapsulation protocols and data formats, daily broadcast message instructions are generated and transmitted to the digital television front-end. After multiplexing and QAM modulation, signals are distributed via wireless terrestrial digital television (DTMB), ensuring terminal device compatibility with digital TV set-top boxes.

Advantages: Digital signal transmission provides good audio quality with low distortion, supports audio-video-text transmission, enables multi-channel insertion with high frequency utilization, leverages existing DVB-C/DTMB systems without separate wiring, maintains relatively low cost, allows multi-channel simultaneous transmission, and supports intelligent addressable terminal control.

Disadvantages: Limited by the reach of cable/terrestrial digital TV networks below county level, where TS stream multiplexing, adaptation, and scrambling conditions restrict platforms without basic infrastructure from transmitting daily broadcast messages, preventing full utilization of emergency broadcast capabilities. The lack of a return channel prevents real-time terminal monitoring. These defects make it unsuitable for regions with poor geographic conditions, and it is only applied in certain areas.

2.5 IP Broadcast Technology

Based on TCP/IP protocol, this pure digital broadcast technology integrates with standard IP networks from a physical structure perspective. Understanding its technical characteristics and requirements before integration ensures smooth implementation. This approach enables full technology integration, enhances emergency broadcast system stability and technical levels, and supports digital audio broadcasting, live streaming, and on-demand functions. Leveraging TCP/IP network advantages optimizes traditional analog broadcast system structures, overcoming limitations in content, space, and functionality.

Advantages: Digital and networked characteristics from program production to signal transmission, strong signal-to-noise processing ensuring noise-free signal handling and transmission, bidirectional transmission enabling manageable and controllable operations (timing, addressing, grouping, point broadcasting), audio file transmission via data packets with multiple broadcast path options, and system software supporting remote monitoring and operation with expandable capacity.

Disadvantages: High server requirements for system software installation, with entire system paralysis possible if problems occur; slow network speeds cause audio interruptions and longer broadcast delays compared to other modes; dedicated chips required for digital audio file decoding increase equipment costs. Despite these defects, IP broadcast technology' s advanced nature has enabled widespread national promotion and application.

2.6 Hybrid Broadcast Technology

Recent multi-mode broadcast technologies primarily employ IP+FM and IP+TS (DVB-C/DTMB) approaches. Years of practice show that IP+FM broadcast signals typically reach town and village levels via IP networks from county-level front-ends, while FM small-scale broadcasting covers the "last kilometer" from villages to villager groups. At the county front-end, broadcast signals are transmitted as IP data packets to administrative villages, then converted to FM signals via adapters for terminal transmission. IP+TS (DVB-C/DTMB) follows similar IP transmission, but TS signals are transmitted directly from county front-ends to terminals rather than from villages, solving the "last kilometer" coverage problem. Both modes enable county-town-village tri-level joint broadcasting and control.

Advantages: IP+FM leverages existing IP network resources while FM solves final coverage; IP+TS utilizes both IP networks and digital TV infrastructure with flexible networking, good audio quality, and addressable control.

Disadvantages: High space frequency resource consumption; affected by cable/terrestrial digital TV network reach below county level, making it unsuitable for areas lacking basic conditions; requires separate emergency broadcast frequency planning, increasing workload; occupies broadcast TV channels for emergency program transmission.

3.1 Current Development Status of Emergency Broadcast Technology

Currently, county-level emergency broadcast systems in China primarily adopt wired IP+wireless FM or wired IP+wireless TS (DTMB) networking modes, covering counties, towns, villages, and villager groups. Only 极少数 counties use 3G/4G streaming mode based on mobile communication networks. While representing essential improvements over analog broadcast technology, these systems remain limited to medium- and small-scale applications with fragmented construction and usage, failing to achieve lightweight, unified, large-scale effects. This fragmentation impedes customer business development and continuous operational needs.

As previously discussed, wired IP+wireless FM and wired IP+wireless TS (DTMB) solutions have obvious defects. Wired IP networks suffer from limited coverage and high standalone construction costs, while wireless FM and TS (DTMB) signals face reduced transmission stability and limited coverage due to frequency resources and terrain, leaving core problems unresolved and restricting system scalability and adaptability.

Broadcasting authorities struggle with streaming media solution development, as both wireless FM and wired IP schemes require "internal digestion," directly affecting collaboration with operators. Consequently, provincial broadcasting authorities have shifted focus to streaming media solutions, emphasizing wired IP+wireless FM and wired IP+wireless TS (DTMB) technologies. According to the "National Emergency Broadcast System Construction Master Plan," they actively improve systems, upgrade technical levels, and innovate models from a modern, long-term development perspective, summarizing past experiences and creating new development approaches.

During innovation, leveraging mobile internet' s bidirectional network characteristics enables streaming solution innovation, addressing emergency broadcast signal transmission challenges through 合理化 implementation. Simultaneously, monitoring broadcast content in real-time and combining traditional broadcast technology' s strengths while addressing weaknesses drives industry progress. Applying IoT technology enhances emergency broadcast technical levels and effectiveness.

3.2 IoT Emergency Broadcast Technology Analysis

3.2.1 The Relationship Between IoT and Internet

The Internet, also called the international network, connects networks through universal protocols to form a logically unified global network. It essentially interconnects computer networks, and mobile internet adds mobile devices (phones, tablets) to servers and computers, enabling connectivity between these devices. The Internet has become ubiquitous in daily life, providing information services such as paperless office work, data uploading, updating, and sharing via computers or phones. Mobile internet integrates mobile communication terminals with the Internet, allowing users to access information and services anytime, anywhere through high-speed mobile networks.

IoT extends and expands upon the Internet, with the Internet and mobile internet remaining its core foundation. If the Internet connects computers, IoT connects all things in the world. Through RFID, wireless communication, and intelligent identification technologies, IoT converts object conditions into parameters for sharing via the Internet, creating a network linking everything. For example, supermarket QR code payments represent a primitive application; evolving further, IoT microchips on products could automatically share location, status, and contextual information. Advanced integration of chips in humans, vehicles, buildings, and furniture enables smart cars, cities, buildings, and homes. Developments in 5G, IPv6, chips, big data, and cloud computing have nearly cleared technical barriers for IoT, heralding an AIoT era.

The distinction is clear: IoT connects things (object-to-object) as internal, self-contained systems, while the Internet connects people (person-to-person) as an open platform for social customers. In emergency broadcast discussions, IoT is often referred to as the Internet, but they differ fundamentally.

3.2.2 Key Technologies for IoT Smart Emergency Broadcast Systems

Implementing emergency broadcast functions on IoT requires designing and developing smart emergency broadcast platform software, front-end hardware equipment, and terminal devices. Due to space limitations, we briefly discuss the main technologies or protocols used in platform software development.

3.2.2.1 Network Protocol: MQTT (Message Queuing Telemetry Transport) IoT devices must connect to the Internet to collaborate with each other and back-end services. MQTT, developed by IBM, is an instant messaging protocol and ISO standard (ISO/IEC PRF 20922) based on a publish/subscribe model. Built on the TCP/IP stack, this client-server message protocol is designed for low-performance remote devices and poor network conditions. Lightweight, simple, flexible, open, and easy to implement, MQTT can connect virtually all networked objects to external systems and has become an IoT communication standard, making it suitable for smart emergency broadcast systems.

3.2.2.2 Network Protocol: RTMP (Real-Time Messaging Protocol) RTMP, based on TCP, is a protocol family including RTMP basic protocol and variants like RTMPT/RTMPS/RTMPE. Designed for real-time data communication, it primarily enables audio-video-data communication between Flash/AIR platforms and streaming media/interactive servers. Supported by software such as Adobe Media Server, Ultrant Media Server, and red5, RTMP is used in smart emergency broadcast systems for broadcast message transmission. Built on TCP or polling HTTP protocols, it acts as a container for data packets in AMT format or FIV video/audio data, with each connection transmitting multiple network streams through different channels using fixed-size packets.

3.2.2.3 Network Infrastructure: CDN (Content Delivery Network) CDN is an intelligent virtual network built on existing infrastructure, representing an optimized network overlay layer. Through edge servers deployed across regions, central platform load balancing, content distribution, and scheduling enable users to obtain content from nearby sources, reducing network congestion and improving access speed and hit rate. Broadly speaking, CDN represents a network service model based on quality and order. By assessing user proximity and server load, CDN ensures highly efficient service delivery. Major operators like AT&T, Deutsche Telekom, and China Telecom have built their own CDN networks. For large-scale smart emergency broadcast systems, sufficient bandwidth resources are essential to reduce latency and ensure viewing quality, with bandwidth depending on traffic control and congestion management. CDN' s adaptability to network resource changes meets smart emergency broadcast system requirements.

3.2.2.4 Architecture: Android JNI (Java Native Interface) JNI, officially introduced in Java SDK 1.1, provides standard interfaces for different

JVMs, enabling Java applications to use local binary shared libraries and expand JVM capabilities while maintaining platform independence without recompilation. JNI defines interaction methods between Java and C/C++ code, allowing Java to call native code. In smart emergency broadcast systems, shortening audio-video development cycles requires bridging platform-independent Java layers with platform-dependent native environments, sometimes necessitating low-level languages like assembly for time-sensitive code called from Java programs. For rapid audio-video communication implementation on Android, the quickest approach is leveraging open-source projects or APIs, as the technology involves complex 底层 components like audio-video capture, decoding, FFmpeg, and media streaming protocols. Demo program APIs provide pure Java interfaces that call kernel shared libraries (.so files, similar to Windows DLLs) via JNI, enabling rapid audio-video communication.

3.2.2.5 Architecture: Microservices Architecture Microservices architecture is a software development technique and SOA variant for deploying applications and services in the cloud. It enables detailed analysis of work components, building independent management systems that optimize structure and enhance stability during operation. Following SOLID principles, the system is divided into multiple small systems that are both independent and interrelated, facilitating business development, management, and iteration. Microservices simplify product delivery and reduce architectural complexity through platform-based deployment, management, and service functions. Each microservice has its own program, collaborating via lightweight devices and HTTP APIs, making it suitable for emergency broadcast applications.

3.2.2.6 Architecture: MQ (Message Queue) MQ is an application communication method that facilitates middleware product generation. Operating on "write" and "retrieve" principles, it stores program data in arrays, providing crucial records for broadcast content improvement and adjustment. Both recorded data and transmission occur without specific connections, reducing difficulty and ensuring stable, effective emergency broadcast message dissemination. MQ enables inter-program communication, forming communication systems through technologies like remote procedure calls. Frequently used in software architecture, MQ is essential infrastructure for distributed internet applications, solving decoupling, asynchronous messaging, and traffic shaping to achieve high-performance, highly available, scalable, and eventually consistent architectures. In microservices architectures, MQ has become a common tool for inter-service communication, with 松耦合 design improving system availability and scalability—offering significant advantages for smart emergency broadcast systems.

3.3 IoT Smart Emergency Broadcast System Architecture

3.3.1 System Architecture Composition

IoT-based emergency broadcast systems, often called smart emergency broadcast systems, consist of three components on 4G/5G IoT networks: cloud servers, broadcast front-ends, and broadcast terminals. Servers deploy on public or local cloud platforms, while front-ends and terminals can be deployed in urban areas (districts, streets, communities, parks, industrial zones) or rural regions (townships, administrative villages, natural villages). Connected to cloud servers via the Internet or mobile internet, users can broadcast content and make announcements through mobile apps, smart microphones, or computer clients, with reception through smart power amplifiers, 4G/5G sound columns, and 4G/5G receivers.

Public cloud deployment ensures front-ends and terminals can access the system almost anywhere with mobile network signals. Beyond public cloud security measures, all control signaling undergoes high-strength encryption, ensuring security, controllability, strong disaster recovery, easy scalability, and support for massive device 接入 with real-time status monitoring and big data analytics-based management. The overall architecture is shown in [Figure 1: see original paper].

Cloud Server: Centered on the smart emergency broadcast platform with all services cloud-deployed.
Broadcast Front-end: Smart emergency broadcast clients, smart microphones, and smart emergency broadcast apps.
Broadcast Terminal: IP/4G/5G multi-mode smart emergency broadcast terminal devices, including smart power amplifiers, 4G/5G sound columns, and 4G/5G receivers.

3.3.2 System Functional Characteristics

The 4G/5G IoT emergency broadcast system encompasses all broadcast technology functions with self-contained, independently operable capabilities. Unlike traditional rural broadcast requiring heavy asset investment and complex multilevel management, this system relies on IP/4G/5G communication pipelines with cloud-based platforms and intelligent two-way terminal control. Key functional characteristics include:

1. **Distributed Deployment:** Typical cloud computing layered architecture design with distributed, clustered deployment for smooth expansion.
2. **Hierarchical Management:** Supports all tree-shaped organizational structures from administrative divisions to enterprises and institutions.
3. **Massive Concurrency:** A single central platform supports unified management of 海量 devices.
4. **Security, Reliability, Manageability, and Controllability:** Platform interconnection with system independence, array-based

self-management, two-way transmission, full status awareness, and single-point controllability.

5. **Simultaneous Live Broadcasting:** Real-time live announcements anytime, anywhere via mobile apps.
6. **Disaster Recovery:** Supports multiple data centers for easy off-site disaster recovery.
7. **Easy Installation and Maintenance:** Plug-and-play functionality manageable by ordinary electricians; contactless configuration and maintenance via mobile app QR code scanning.

3.3.3 System Advantages and Value

1. **Network Coverage:** With construction by major operators (telecom, mobile, Unicom, broadcasting), 4G/5G IoT coverage extends to every corner of townships, villages, and groups, free from regional, scale, and interaction constraints.
2. **Infrastructure Costs:** Compared to traditional IP broadcast products, public cloud rental eliminates the need for extensive 机房 infrastructure and hardware/software procurement, significantly reducing investment.
3. **Engineering Construction:** Terminal installation is simple with minimal hardware/software dependencies, requiring only basic network configuration and low engineering expertise.
4. **Operations and Maintenance:** Pay-per-use traffic fees for public cloud and terminals shift maintenance risks to providers, allowing customers to focus on daily broadcast operations with lower costs and risks.
5. **Customer Value:** The 全新 architecture offers advanced technology, improved stability, transmission quality, and security. 4G/5G IoT coverage provides natural ecological support for business expansion with convenient upgrades and expansion.
6. **System Functions:** Application modes and product experiences achieve qualitative leaps, enabling centralized management and county-township-village tri-level joint broadcasting with two-way channel-based remote terminal monitoring.
7. **Market Promotion:** Compared to traditional IP broadcast products, standardized technical solutions enable rapid response for pilot projects and customer experiences, lowering market promotion thresholds.
8. **After-sales Maintenance:** Cloud platforms provide immediate response and technical support for customer feedback, enabling rapid remote diagnosis of terminal issues and reducing communication and time costs while requiring lower maintenance technical capabilities.
9. **Broadcast Dissemination:** Supports ultra-large-scale terminal deployments across vast geographic spans, large audiences, and diverse industries, providing broad space and natural advantages for content dissemination.
10. **System Interaction:** Enables out-of-the-box usage without additional management, greatly simplifying daily operations and eliminating previous constraints on business development and continuous operations.

11. **Commercial Value:** Operators can deeply analyze user content needs based on their business development and positioning, forming a content operation ecosystem that delivers sustainable value to users and creates significant commercial prospects.

3.4 Smart Emergency Broadcast Application Scenarios

For counties and cities, the system 主要包括 the emergency broadcast platform and smart emergency broadcast loudspeaker system. The emergency broadcast platform connects to the smart emergency broadcast front-end to achieve national standard-compliant functions. While national standards don' t explicitly require smart emergency broadcast systems, manufacturer-developed systems generally implement national standard wired IP broadcast functions.

4G/5G smart emergency broadcast has been promoted in some counties and cities using two technical modes: public cloud and local cloud. While both modes achieve consistent functions technically, practical applications reveal the following primary scenarios:

3.4.1 Rural Application Scenario 1

Counties and cities construct emergency broadcast platforms and smart emergency broadcast loudspeaker systems meeting national standards, reserving interfaces for upper-level emergency broadcast platforms and connecting horizontally with functional departments' (emergency, meteorology, water resources, public security) early warning platforms. The smart emergency broadcast loudspeaker system implements three-level (county-township-village) or two-level (county-township) joint broadcasting and control, with villager group terminals using integrated cable, wireless addressable, and 4G/5G reception.

3.4.2 Rural Application Scenario 2

Counties and cities construct smart emergency broadcast loudspeaker systems connected horizontally with functional departments' early warning platforms. The system implements three-level or two-level joint broadcasting and control, with villager group terminals using integrated cable, wireless addressable, and 4G/5G reception.

3.4.3 Urban Street and Community Emergency Scenario

Counties and cities construct smart emergency broadcast loudspeaker systems implementing three-level (county-street-community) or two-level (county-street) joint broadcasting and control, with community terminals generally using wireless addressable and 4G/5G sound columns.

3.4.4 Urban Street, Community, and Park Scenario

Counties and cities construct smart emergency broadcast loudspeaker systems implementing three-level (county-street-community/park) or two-level (county-street) joint broadcasting and control, with community and park terminals using wireless addressable and 4G/5G sound columns.

3.4.5 Urban Public Security Emergency Rescue Scenario

Counties and cities construct smart emergency broadcast loudspeaker systems with a primary control platform at the county public security command center, integrated with video surveillance for rescue command. Community and park terminals use wireless addressable and 4G/5G sound columns.

Beyond public emergency response, emergency broadcast in the media convergence era—especially with big data and cloud technology—should adopt a "peacetime-wartime combination" strategy. Researching audience daily needs ensures popularity during normal times and responsiveness during emergencies. Against the triple-network convergence backdrop, new technologies including interactive technology, video cloud, and big data analytics will diversify emergency broadcast content and forms. Future development should advance steadily in standardization, technological innovation, and application methods.

In standardization, 4G/5G emergency broadcast technology, converged media technology, UAV broadcast technology, vehicle-mounted mobile broadcast technology, and public welfare mobile terminal broadcast technology should be incorporated into national emergency broadcast standards to ensure seamless vertical and horizontal connectivity. Technological innovation should fully demonstrate 5G IoT advantages in emergency broadcast systems, expanding transmission means through network broadcast programs, digital audio broadcasting (DAB), Weibo, WeChat, and mobile apps. In application methods, we should gradually achieve integrated construction-management-maintenance, multi-dimensional networking (water resources, meteorology, public security), urban-rural integration (streets, communities, townships, villages), diversified content, intelligent terminals (collecting environmental data), value-added services, flattened structures, and build a provincial unified smart voice project under Party committee management to occupy the public opinion 宣传阵地 more extensively and deeply.

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Note: Figure translations are in progress. See original paper for figures.