Broadband Wireless Communication System Solutions for Industry Applications: Postprint

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Abstract

This paper proposes a broadband wireless communication system solution for industry applications, elaborating in detail on the network architecture, functional components, and key technologies adopted in this solution, and introduces the typical application scenarios of this network system, the R&D achievements obtained thus far for this solution, and the next-step R&D deployment plans.

Full Text

Preamble

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A Broadband Wireless Communication System Solution for Industry Applications

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Abstract: This paper proposes a comprehensive broadband wireless communication system solution tailored for industry applications. We elaborate on the network architecture, functional components, and key enabling technologies, and introduce typical application scenarios, current R&D achievements, and future development plans for this network system.

Keywords: industry applications, broadband wireless communication, network architecture

1. Background and Requirements for Industry-Oriented Broadband Wireless Communication Systems

Rapid advancements in wireless communication technology across bandwidth, coverage, and service support capabilities have created vast opportunities for applications in military communications, emergency communications, wireless cities, and other domains. Compared with conventional civilian systems, broadband wireless communication systems for industry applications exhibit several distinctive characteristics.

First, the communication environment in certain industry scenarios—such as mountainous regions or battlefields—features harsh electromagnetic conditions, necessitating optimized signal processing and wireless resource management schemes, along with supplementary technologies to enhance "communication-on-the-move" and "communication-under-interference" capabilities. Second, network deployment demands flexible, easily deployable architectures with strong resilience and self-healing capabilities. Distributed self-organization technologies are required to enable rapid network construction and mobility, accommodating the real-time topology changes characteristic of industry applications. Third, many industry networks lack the conditions for advance planning or manual optimization and maintenance during operation, mandating intelligent control and management technologies for plug-and-play functionality, including self-configuration, self-management, and self-optimization to improve network survivability. Fourth, service support must accommodate diverse cross-media applications including short messages, formatted commands, files, voice, images, video, environmental situational awareness, and information sharing, with some imposing stringent requirements on transmission accuracy and real-time performance. This necessitates specialized designs in wireless resource management and end-to-end QoS guarantee mechanisms to provide hierarchical, quality-assured transmission services. Finally, certain strategic application domains require localized R&D, equipment development, and services to better satisfy security and confidentiality requirements, effectively preventing information leakage from technology import, product procurement, or technical services.

To address these specialized requirements, we must develop an integrated solution encompassing access, transmission, and intelligent control management to meet the diverse needs of different communication environments, deployment characteristics, and service types in industry communication systems. The proposed solution must provide: an integrated architecture including wireless access, backbone transmission, and intelligent control; anti-interference capability for various wireless environments, especially under jamming; high-bandwidth service capability for both access and transmission to support diverse services; wide coverage through extensive wireless access and distributed multi-hop transmission; "communication-on-the-move" support for high mobility and flexible deployment; self-organization and self-healing for enhanced resilience; rapid deployment and automatic configuration for true plug-and-play operation; secure transmission through customized encryption/decryption and authentica-

tion mechanisms; seamless integration with satellite systems and the Internet via control gateways; cross-media service support with hierarchical end-to-end QoS guarantees; and independent R&D for strategic security.

[Figure 1: see original paper] Network Architecture for Industry-Oriented Broadband Wireless Communication Systems

2. Network Architecture and System Overview

As illustrated in Figure 1, the network architecture for industry-oriented broadband wireless communication systems comprises four main components: the terminal and service system, broadband wireless access system, distributed backbone transmission system, and intelligent control management system [1].

The terminal and service system interfaces directly with users. Our solution supports multiple terminal types, including WiMAX[1] [2] and LTE[2] [3] terminals that connect directly to the broadband wireless access system, as well as Ethernet, ad hoc networks, WiFi[3], and IoT terminals that forward user traffic via wired or wireless IP connections to WiMAX/LTE Customer-Premises Equipment (CPE) or outdoor terminals, which then wirelessly relay data to the broadband wireless access system.

The broadband wireless access system, based on WiMAX/LTE technologies, provides high-bandwidth, wide-coverage, high-mobility wireless access services with QoS guarantees. Additionally, Femtocell [4] technology is employed to enhance indoor coverage and eliminate communication dead zones.

The distributed backbone transmission system is built upon Mesh [5] technology, interconnecting multiple broadband wireless access systems through wireless, distributed, multi-hop connections to extend overall network coverage. Leveraging Mesh' s decentralized, self-organizing characteristics enhances network resilience, self-healing capability, and rapid deployment while reducing maintenance costs.

The intelligent control management system is a logical subsystem whose functions are distributed across access devices, backbone transmission devices, and control management equipment to enable self-management, self-configuration, self-healing, and self-optimization throughout the network, meeting the plug-and-play requirements of industry systems. This system also includes gateway devices for centralized control of private networks and interconnection with other networks.

[Figure 2: see original paper] Diverse Terminal Application Forms

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3.1 Multi-Modal Terminal System

Our solution accommodates multiple standards and modes to expand application scenarios. By employing "all-IP" WiMAX and LTE technologies in the

broadband wireless access system, we support not only standard WiMAX and LTE terminals but also IP-based wired and wireless technologies including Ethernet, ad hoc networks, WiFi, ZigBee , and SIP . These terminals interconnect with WiMAX/LTE terminals via IP technology, with the WiMAX/LTE terminals serving as wireless aggregation nodes for long-distance transmission of terminal data, as shown in typical scenarios in Figure 2.

3.2 Broadband Wireless Access System

The broadband wireless access system builds upon mainstream broadband wireless technologies, with R&D optimizations for industry-specific scenarios to meet the broadband wireless access and service requirements of large-scale fixed or mobile users. It enables high-speed data transmission from terminal systems and delivers control commands from the intelligent management system accurately. The system employs WiMAX and LTE technologies for last-hop broadband wireless access, offering high transmission bandwidth for diverse services, wide coverage, and high mobility support. Femtocell technology enhances indoor and dead-zone wireless coverage, improving network service capability. Key technologies include:

WiMAX-based broadband wireless communication systems and equipment: WiMAX is a mainstream broadband wireless technology with advantages in communication range, transmission rate, and mobility speed, offering broad prospects in private networks and emergency communications. We have optimized the protocol stack software and signal processing components for various private network applications to build customized equipment meeting industry requirements.

LTE-based broadband wireless communication systems and equipment: LTE represents the future mainstream broadband wireless technology, offering stronger advantages in network deployment, mobility support, and industry backing. With strong national support and industry collaboration, LTE technology is maturing rapidly. Our private network system will gradually adopt LTE as the primary access technology in coming years.

Low-cost Femtocell communication systems: Private systems typically feature numerous dispersed users and challenging communication environments. Our solution employs low-cost Femtocell devices deployed in barracks, office buildings, and other indoor environments to enhance wireless coverage and enable low-BER data transmission. In harsh environments such as mountains, forests, or battlefields where WiMAX/LTE coverage has dead zones, low-power portable Femtocell systems effectively enhance local wireless coverage, enabling seamless communication.

Enhanced wireless penetration and anti-interference technologies: We have researched enhanced wireless penetration and anti-interference technologies, employing frequency hopping, frequency reduction, and directional antennas to

improve equipment penetration and anti-interference capabilities for diverse industry deployment needs.

Equipment miniaturization technology: In military and emergency communications, broadband wireless access equipment must be miniaturized for rapid deployment via airdrop, airship, or UAV to quickly reconstruct damaged access networks, making miniaturization a key research focus in private communications.

3.3 Distributed Backbone Transmission System

The distributed multi-hop transmission system (Mesh) is crucial for meeting self-organization, resilience, and flexible deployment requirements. Conventional solutions typically employ wired backbone systems (e.g., fiber optic or powerline communications) that suffer from long restoration periods and inflexible deployment after disasters. Our project builds a wireless, self-organizing, distributed multi-hop transmission system based on Mesh technology. Wireless Mesh is an IP-based wireless broadband technology combining broadband communication and ad hoc network advantages, supporting multi-point-to-multi-point mesh structures with intelligent capabilities for self-organization, self-healing, multi-hop cascading, and node self-management. These advantages enable rapid deployment, self-organizing management, and multi-hop wide-area transmission in private network environments. Specific technologies include:

Distributed networking technology: The core of Mesh technology is achieving distributed multi-hop transmission in wireless environments, making distributed networking among Mesh nodes a fundamental challenge. Key technologies include node synchronization, distributed resource sharing, end-to-end QoS guarantee mechanisms, and multi-hop routing.

Distributed multi-hop routing technology: Routing is fundamental to distributed multi-hop transmission. In emergency and military communications with poor wireless link conditions, traditional hop-count-based path selection algorithms cannot meet special requirements. Our system designs a link-state-based distributed multi-path layer-2 routing algorithm optimized for private network scenarios.

Node interference coordination technology: Unlike centralized point-to-point systems such as WiMAX and LTE, distributed self-organizing Mesh networks lack central control nodes. We have designed an interference coordination mechanism enabling peer-to-peer node coordination to reduce mutual interference, meeting the irregular networking requirements of private systems.

Multi-interface, multi-channel technology: Our Mesh technology is applied in backbone transmission with high bandwidth requirements. The system employs multi-interface, multi-channel technology with multi-channel wireless resource management to enable simultaneous transmission on different frequencies from a single Mesh node, increasing network capacity [6].

3.4 Intelligent Control Management System

In certain application scenarios, personnel cannot be deployed for installation, configuration, or maintenance, while network topology and communication environments change rapidly, requiring nodes to perform self-management according to network needs. Therefore, developing intelligent control management technology is critical. The intelligent control management technology is distributed across access devices, backbone transmission devices, and control management equipment to enable self-management, self-configuration, self-healing, and self-optimization, achieving plug-and-play functionality, expanding environmental adaptability, and reducing maintenance costs. Specific technologies include:

Intelligent network control management system: This system focuses on controlling and managing terminal, access, and transmission devices, including power control, parameter configuration, intelligent isolation, and load balancing. It operates at the network control center, interconnecting with edge Mesh nodes via wired or wireless connections.

Node self-management, self-configuration, self-healing, and self-optimization technology [7]: In emergency communications and other private network applications, communication nodes are deployed on-demand and irregularly at locations inaccessible to personnel. Therefore, node self-management capabilities become essential, including automatic node identifier assignment, automated initialization parameter configuration, adaptive adjustment of node information and channel parameters during operation, and self-healing/self-isolation under fault conditions, enabling adaptive survival in harsh environments without human intervention.

Smart gateway and external interconnection system: Our network' s WiMAX/LTE and Mesh technologies are based on an all-IP platform, providing excellent extensibility and interconnection capabilities. Gateway devices interconnect the system with satellite communications, SIP-based IP Multimedia Subsystem (IMS) , and public Internet systems, expanding application scenarios for the private network.

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4. Typical Application Scenarios

This solution can be applied in military communications, smart grids, emergency communications, forest fire monitoring, and wireless city construction. The Institute of Computing Technology, Chinese Academy of Sciences (ICT-CAS) Wireless Communication Technology Research Center (hereinafter "Wireless Center") has already applied R&D achievements with partners across multiple industries. Two typical scenarios are described below.

4.1 Military Application

A typical military application scenario is shown in Figure 3 [Figure 3: see original paper]. UAVs and airships can be equipped with WiMAX/LTE base station access equipment and Mesh backbone transmission devices to form a mobile distributed Mesh backbone network for multi-hop data forwarding. During troop operations or movement, each vehicle/vessel carries a WiMAX/LTE access terminal (aggregation node). Individual soldiers can connect via ad hoc or WiFi handheld radios to WiMAX/LTE terminals, or directly via handheld WiMAX/LTE terminals. WiMAX/LTE terminals transmit data to base station equipment on UAVs/airships via broadband wireless technology, which then bridges IP data to Mesh backbone devices for multi-hop forwarding to other combat units, enabling integrated air-ground-sea operations.

4.2 Smart Grid Application

Our private network system supports the construction of a low-cost, rapidly deployable smart grid communication system for information collection and intelligent control management. WiMAX/LTE broadband technology enables comprehensive grid operation data collection and real-time sharing, supporting real-time equipment control and intelligent regulation to balance power generation and consumption, preventing equipment damage from data inconsistencies. The high bandwidth also facilitates real-time video transmission from fault sites to assist control centers in analyzing equipment damage and repair difficulty. Distributed wireless multi-hop Mesh technology enables long-distance wireless backhaul of collected data and control commands, enhancing deployment flexibility and timeliness while reducing costs. Control management technology enables real-time monitoring and management of power distribution and transformation systems, meeting intelligent management requirements.

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5. R&D Achievements and Future Plans

Since 2004, the Wireless Center has conducted R&D on this industry-oriented broadband wireless communication system, undertaking key technology research and equipment development across broadband wireless access, distributed backbone transmission, and intelligent control management systems.

5.1 Terminal and Broadband Wireless Access System

Baseband chips and terminal equipment development: Based on R&D in signal processing and wireless resource management, the Wireless Center successfully developed a WiMAX terminal solution and prototype equipment in 2008 with partners, and launched LTE terminal baseband chip and solution R&D in 2009 to enrich terminal types.

Wireless resource management key technology and protocol stack software development: Wireless resource management and protocol stack software are core components critical for equipment performance and hierarchical QoS support. The Wireless Center has successfully developed protocol stack software systems for WiMAX/LTE/TD-SCDMA/Mesh communications, laying a solid foundation for equipment development.

WiMAX/LTE base station access equipment development: The Wireless Center has successfully developed WiMAX broadband wireless communication base station equipment and conducted multiple field trials, with small-scale LTE base station equipment currently under development.

Femtocell equipment development: The Wireless Center has successfully developed TD-SCDMA Femtocell equipment for industry applications with multiple partners, with LTE-based Femtocell equipment currently under development.

5.2 Distributed Backbone Transmission System

Mesh distributed networking technology research: In Mesh distributed networking, the Wireless Center has designed a multi-interface, multi-channel Mesh MAC protocol, link-state-based layer-2 routing protocol, and mechanisms for node synchronization, multi-channel sharing, and QoS guarantee, successfully developing Mesh MAC and routing protocol stack software. Additionally, a Mesh network system-level simulation platform based on NS2[1] has been developed to provide a verification environment for key technology research and network deployment.

Distributed Mesh communication equipment development: Based on Mesh distributed networking technology and protocol stack R&D achievements, the Wireless Center is jointly developing distributed Mesh backbone transmission equipment with partners.

5.3 Intelligent Control Management System

Node self-management, self-configuration, self-healing, and self-optimization technology research: The Wireless Center has designed an intelligent control management signaling system including automatic node identifier/system parameter configuration, distributed domain name services, intelligent network selection and handover, runtime parameter self-optimization, and self-healing/self-isolation control under fault conditions, initially achieving plug-and-play and manageable/controllable network nodes.

Smart gateway control management equipment development: After more than a year of R&D, the Wireless Center has successfully developed a unified smart gateway solution integrating TD-SCDMA, WCDMA, and SIP terminals. The gateway supports multiple standard 3G terminal accesses, providing

voice, video, and data services, and supports SIP protocol for interconnection between private and other networks.

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6. Conclusion

In the next phase, we will focus on LTE baseband chip and terminal solution R&D, LTE Femtocell equipment development, and distributed Mesh equipment development and optimization, aiming to complete the entire industry-oriented broadband wireless communication system within two years.

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Footnotes

[1] Worldwide Interoperability for Microwave Access
[2] 3GPP Long Term Evolution, Third Generation Partnership Project Long Term Evolution
[3] Wireless Fidelity, a technology based on IEEE 802.11 standards for wirelessly connecting terminals such as personal computers and handheld devices
Mesh network, wireless Mesh also called multi-hop network, where any wireless device node can simultaneously serve as an access point and router
ZigBee (definition not provided in original text)
Session Initiation Protocol
IP Multimedia Subsystem
Mesh MAC protocol

Network Simulator version 2, an open-source, free software simulation platform for network technologies

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