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黄 铭 主编

# 边境无线电监管示范与创新

云南大学出版社
YUNNAN UNIVERSITY PRESS

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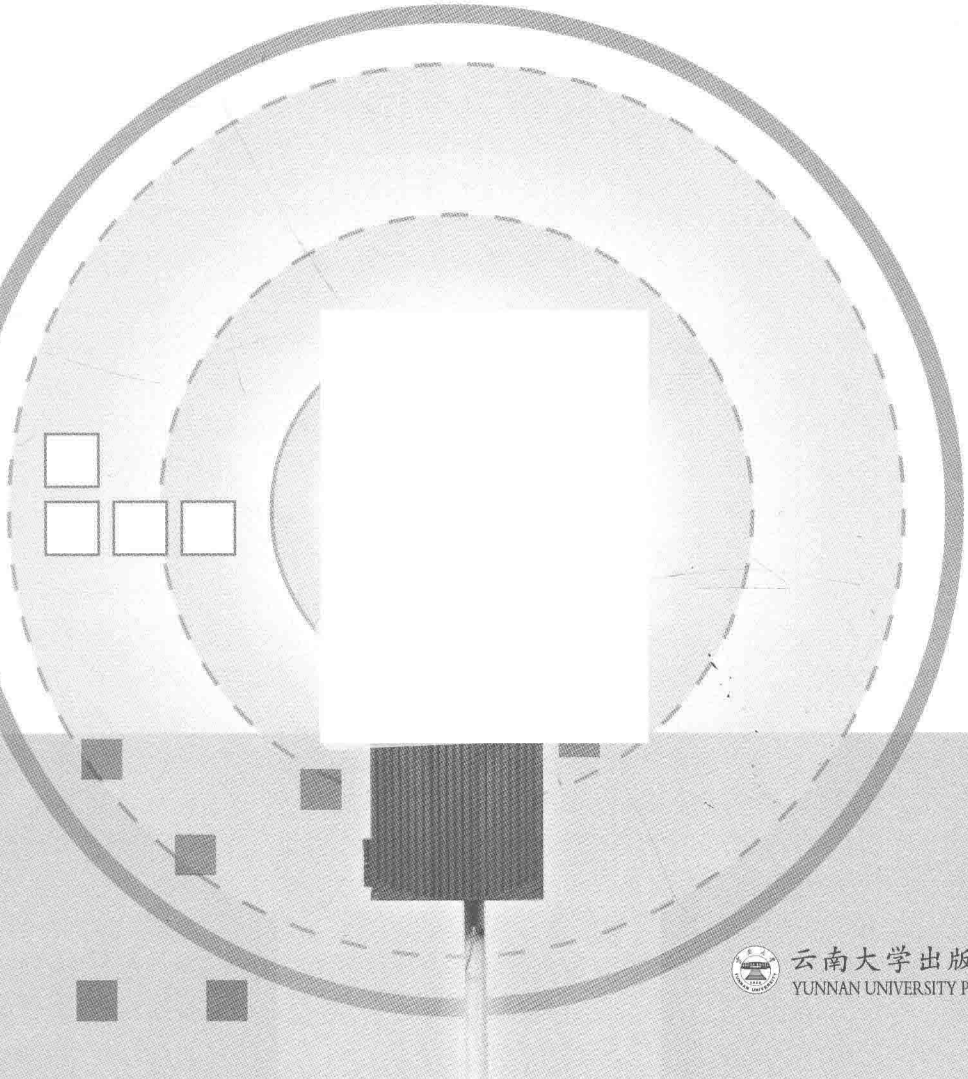

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黄　铭　主编

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邮　　编：650091
电　　话：（0871）65031071　65033244
网　　址：http://www.ynup.com
E－mail：market@ynup.com

**主　笔　人：** 黄　铭　鲁倩南　杨晶晶

# 序

转眼之间，我从事无线电管理工作近二十载。这些年来，我国经济飞速发展，无线电技术和业务在社会各领域的应用愈加广泛和深入，与之配套的无线电管理工作，所担负的管理任务愈加繁重、愈加多元。红河州无线电监测设施从一个移动监测站、一套可搬移式监测系统、一台便携式监测设备起步，到逐步建成以频谱资源管理为核心，技术较为先进、布局相对合理、功能基本齐全的无线电技术监管体系，为无线电事业健康发展和边境电磁频谱安全保驾护航。全州无线电管理战线的广大干部职工，在各级党委、政府和省无线电管理机构的正确领导下，团结奋进，开拓进取，求真务实，争创一流，圆满完成了各项工作任务，为红河州经济社会发展做出了积极贡献。

很多人说无线电事业寂寞、乏味、平凡，很难有创新，更谈不上卓越。而红河无线电人用昂扬的斗志、饱满的激情抒写着“务实中开拓创新，平凡中孕育卓越”。多年来，云南省无线电管理工作一直是全国无线电管理战线的一面旗帜，而红河州无线电管理工作正是云南省无线电事业发展中的一颗明珠。无论是执行日常无线电监管任务，还是完成边境无线电管理工作，红河无线电人在看不见的战线上用汗水映射出、用决心演绎出、用热爱诠释出“敢为人先、迎难而上”的气魄。

红河州地处云南省东南部，与越南接壤，边境线长 848 千米，中越两国在河口县仅有约 20 米宽的红河相隔。90 年代中后期以来，越南经济发展迅速，边境一线广播、电视、移动通信信号交叉覆盖现象较为普遍。2000 年开始，国家无线电管理机构为了解决中越两国在边境地区出现的频率干扰问题，启动了中越边境地区无线电频率协调会谈，该会谈截至目前已经成功举办了 13 次。在每年协助国家无线电管理机构开展的边境电磁环境测试、边境地区无线电频率调查及评估等涉外无线电管理工作中，需要安排大量的人力、物力。在红河州无线电监测网建设中，我们一直将边境一线作为布局的重点，已在护卫国家权益、维护社会稳定、促进边疆经济发展中发挥了重要作用。但由于中越边境线犬牙交错，地貌复杂，山高谷深，沟壑纵横，按照常规的大区制建站方案，不仅造价高、升级改造困难，而且高低端监测范围差别大，制约了红河州边境无线电监测网效能的发挥。

我是云南大学 1989 年毕业的校友。2016 年 4 月，得知云南省无线电监测中心与云南大学积极合作，依托联合共建的云南省高校谱传感与边疆无线电安全重点实验室（以下简称“实验室”），协作开展了谱传感等新一代无线电监测理论和技术研究，研究成果多次荣获云南省自然科学奖、科技进步奖后，便主动与母校取得了联系。赴实验室调研交流后得知，云南省工信委 2015 年承办的“边境区域无线电管理技术设施建设及投资需求研究”国家课题，也是实验室参与完成的，课题提出的基于物联网的智能边疆无线电监管网建设思路被纳入了《国家无线电管理规划（2016—2020）》和《云南省无线电事业发展“十三五”规划》。

实验室基于谱传感技术在“互联网＋边境无线电监管”方面的探索引起了我的关注。如果能够把这些理论成果与红河州边境无线电监管工作实际相结合，运用大数据、移动互联、物联网等新一代信息技术，解决新的时代背景下红河中越边境无线电监管实际问题，具有很强的现实意义。于是，促成了两个月后红河州无线电管理办公室与实验室的第一个合作课题——“基于谱传感的边境电磁频谱监管关键技术研究”。课题成果很有针对性，技术路线很具体，为红河中越边境无线电监管朝着精细化、主动化、人性化，应用“信息一体化”方向发展奠定了坚实的基础。一个想法随之萌生，如果将研究成果实践化，在红河州顺利搭建一套示范系统，无疑会对边境无线电管理决策科学化和边境无线电技术设施智能化起到十分积极的推动作用。说干就干，我们分别到云南省工信委、云南省无线电监测中心进行了专题汇报后，这一想法得到了他们的充分肯定和大力支持，从而有了同实验室的第二次合作——“红河州基于谱传感的边境电磁频谱监管示范系统”。接下来的七个月时间里，我们同云南大学并肩作战，攻坚克难，看过晨曦里的朝霞，守过五更天的繁星，敢于创新引领行业发展。功夫不负有心人！2017 年 6 月，河口县诞生了云南省乃至全国第一个基于谱传感的边境智能无线电监管系统！无线电行业“政产学研用”紧密结合的技术创新体系顺利构建！更令我为之振奋的是，为切实加强“十三五”期间边海地区无线电管理技术设施建设，工信部无线电管理局编制了《边海地区无线电管理技术设施建设工程专项规划（2017—2020 年）》，其中提出的网络架构、建设思路与我们的示范系统建设内容一致！

示范系统建设过程中，得到了云南省工信委、云南省无线电监测中心的悉心指导，得到了红河州铁塔公司、红河州移动公司、河口县工信局的积极配合，更是得到了我的母校——云南大学的鼎力支持。目前，示范系统运行情况良好，得到了国内外专家的高度评价。2017 年 10 月，第 13 次中越边境地区无线电频率协调会谈召开前，从示范系统中提取了红河州河口县中越边境时间连续、频谱完整、要素齐全的实时监测数据，大大降低了边境电磁环境测试的人工参与度，示范效应显著！

无线电管理是一项充满挑战性的工作。近二十载光阴荏苒，这份事业积淀了我深厚的感情，赋予了我沉甸甸的责任感、使命感和荣誉感。作为示范系统的阶段性总结，我们将取得的一些成绩进行了梳理，推出这本论文集，为行业发展提供一些思路，同时，也算是我为母校“双一流”建设略尽绵薄之力！

红河州无线电管理办公室主任

2018 年 2 月 11 日

# 前言

本书收录了云南省高校谱传感与边疆无线电安全重点实验室2014—2017年在“互联网+边境无线电监管”方面的部分研究成果。全书共分为三个主题，包含了红河州基于谱传感的边境电磁频谱监管示范系统(以下简称“示范系统”)研究依托的理论成果，又涵盖了示范系统开发过程中形成的技术和专利。研究工作得到了国内外专家的广泛好评，部分成果达到国际领先水平。

第一个主题为示范系统研究的理论依据，共收录了发表的7篇英文论文和5篇中文论文。其中，论文1为Radio Science(无线电科学)杂志封面论文，文中首次提出了采用谱传感节点，基于物联网、大数据和云计算技术开展智能无线电监管网的建设思路，并展示了示范系统原型。示范系统成为全球第一个公开发表的集成了频谱管理和频谱监测的智能决策支撑系统，引起了国外权威机构和专家的关注，被美国Earth & Space Science News(地球与空间科学新闻)优选为“研究焦点”进行了评述(见附件1)。论文2是受International Union of Radio Science(国际无线电科学联盟)亚太无线电科学大会邀请发表的论文，提出了无线电固定监测站在线测量和校准的方法，作者代表组委会担任“无线电干扰及无线电频谱”分会主席，对国内外无线电频谱监测现状进行了论述。论文3提出了一种协同压缩传感模型，通过多传感器协同工作，提高了对异常无线电发射信号的检测率。论文4提出了一种参与式感知中查询逻辑分离存储的设计方案，可以有效保护隐私，并获得了美国专利。论文5－7分别阐述了基于三稳随机共振和量子粒子群算法的新型频谱感知方法、基于USRP的频谱监测平台和基于C/S架构的黑广播自动监测预警系统。论文8－12研究了基于接收信号本征值的无线电信号协同检测和压缩传感方法、基于最优延时和多天线的并行检测、频谱数据的压缩传感、多天线智能谱感知和无线电频谱数据分类展示方法。

第二个主题围绕“互联网+边境无线电监管”展开，共收录了5篇论文。论文13总体上论述了“互联网+无线电监管”到底该如何来“+”的问题，提出“+”的不仅仅是互联网技术，更是互联网思维。论文14阐明了什么是谱传感，具体描述了在新的时代背景下，更贴合无线电监管工作实际的这种基于知识驱动的无线电监管方法。论文15－17由受云南省工信委委托完成的“边境区域无线电管理技术设施建设及投资需求研究”国家课题衍生而来，连续发表于《中国无线电》杂志。题为《边境电磁环境监管任重道远》和《融合发展互联网+无线电打造智能边疆无线电监管网》的文章被中国通信产业的权威主导媒体《人民邮电》报连续转载(2016年2月17日，2016年3月2日)，提出的融合发展模式引起了国家有关部委的关注，其中，论文16被中共中央网络安全和信息化领导小组办公室官方网站全文转载(见附件2)，并获工业和信息化部内参约稿，这是无线电安全助力国家安全迈出的重要一步。基于“互联网+”提出的以谱传感节点为支撑、大数据采集分析展示平台(云计算平台)为重点的

智能边境无线电监管网建设思路被纳入《国家无线电管理规划(2016—2020)》和《云南省无线电事业发展“十三五”规划》。

第三个主题与示范系统开发紧密相关，收录了发表的5篇英文论文、3篇中文论文及15份知识产权保护相关资料。论文18－25涉及小型化天线设计方法和无线OAM传输系统。在示范系统开发过程中，实验室十分注重保护知识产权，共申请了6项专利、8项计算机软件著作权和1项软件产品认证(见附件3)。在示范系统开发过程中，实验室组织团队参加了第二届云南省创新创业大赛暨第五届中国创新创业大赛云南地区赛，荣获团队组一等奖，并代表云南省参加全国赛荣获优秀团队奖(见附件4)，获得了云南省科技厅专项经费支持，成为“政产学研用”结合的典范。

本书可供从事无线电管理、无线电监测及相关专业人员参考。

# 目　录

论文 1

# State-of-the-art and Challenges of Radio Spectrum Monitoring in China

**Q. N. Lu[1,2], J. J. Yang[1], Z. Y. Jin[2], D. Z. Chen[2], and M. Huang[1]**

1. Wireless Innovation Lab of Yunnan University, School of Information Science and Engineering, Yunnan University, Kunming, Yunnan, China

2. Yunnan Provincial Industry and Information Technology Commission, Kunming, Yunnan, China

Corresponding author: Ming Huang (huangming@ynu. edu. cn)

**Abstract**: This paper provides an overview of radio spectrum monitoring in China. Firstly research background, the motivation are described and then train of thought, the prototype system, the accomplishments are presented. Current radio spectrum monitoring systems are man-machine communication systems, which are unable to detect and process the radio interference automatically. In order to realize intelligent radio monitoring and spectrum management, we proposed a Internet of Things based spectrum sensing approach using information system architecture, and implemented a pilot program, then some very interesting results were obtained.

## 1 Introduction

Radio monitoring is the basis of spectrum management. The radio wave is invisible, intangible and susceptible to radio interference. Spectrum monitoring helps spectrum regulators to plan and use frequencies, avoid incompatible usage, and identify sources of harmful interference. It is a growing problem due to the growing number of spectrum uses. As early as 1820s, the United States made the radio spectrum frequency allocation chart of 0 ~ 60MHz, began to construct spectrum monitoring system[1,2], and enacted the Radio Act of 1927. China began large-scale construction of monitoring stations in 1990s. Through twenty years of development, a national spectrum monitoring system has been built, which plays a critical role in performing all the routine or special monitoring tasks and basically meets monitoring requirements in the frequency range of 20MHz ~ 3000MHz band[3]. Incumbent spectrum monitoring systems comply with the International Telecommunication Union (ITU) guidelines in design and construction[4], which are typical man-machine communication systems, without capabilities of automatic locating, detecting and processing the radio interference. Radio Monitoring Transfer Protocol (RMTP) is applied among multiple monitoring facilities from different manufacturers to achieve interoperability, but the application layer protocol has not been defined[5].

In June 2013 Executive Memorandum on Expanding America's Leadership in Wireless Innovation, President Obama directed the National Telecommunications and Information Administration (NTIA) to design and conduct a pilot program to monitor spectrum usage in real time in selected communities throughout the U. S.. Afterwards, NTIA invested a Spectrum Monitoring Pilot Program[6]. In China, the Central Leading Group for Internet Security and Informatization was established in February 2014, which is chaired by President Xi Jinping. This initiative enhanced the security of cyberspace into national strategies in China. To better serve and integrate into the National Cyberspace Security Strategy, Bureau of Radio Regulation of the Ministry of Industry and Information Technology conducted a research project in March 2015 to assess state-of-the-art of construction in radio monitoring equipments deployed in borderlands of China. We undertook the project and found problems of existing systems, then proposed solutions[5].

This paper provides high-level descriptions of the project in China, and describes a real-time spectrum monitoring system based on Internet of Things (IoT) and cloud computing (or big data). The intelligence solutions were reflected in the State Radio Management Plan (2016 ~ 2020) of China[3]. And a prototype system was constructed in Honghe Hani and Yi Autonomous Prefecture of China.

## 2 State-of-the-art of Radio Spectrum Monitoring

The national spectrum monitoring system, which is combined withfixed, remote, unmanned and mobile monitoring stations and transportable, portable radio monitoring equipments, is the strong technical support to fulfill spectrum management functions in China[5]. Existing problems of current spectrum monitoring systems include[5,7,8]: (1) mainly consisting of large and expensive monitoring equipments, with which to build large-scale spectrum monitoring systems would be high cost and inefficient; (2) not information systems but communication systems, and complying with RMTP just for data transmission, in which facilities transfer monitoring data originally without processing; and (3) little effort to dig large amounts of spectrum data acquired by monitoring equipments for all benefits, especially to utilize the time and location dimensions of the radio-frequency.

## 3 Challenges of Radio Spectrum Monitoring

To solve the above problems, experts have come up with many solutions. In 2012, D. Z. Chen et al. proposed a radio monitoring approach based on spectrum sensing in real time in specific areas[9]. Subsequently, the approach was implemented and the project won Yunnan Provincial Science and Technology Progress Award in China. In 2015, L. Yang et al. discussed how to design a platform which can store, manage, retrieve and analyze radio coverage data based on B/S model by using database and Baidu map JavaScript API technology and combining with the characteristics of radio monitoring equipments[10]. Although China has put forward the concept of grid monitoring for almost 10 year, there is no report on the implementation of radio spectrum monitoring systems based on IoT and cloud computing (or big data).

In 2015, M. Cotton et al. provided an overview of the Spectrum Monitoring Pilot Program in the U. S. and described the development of a federated Measured Spectrum Occupancy Database architecture and progress in RF sensor R&D[7]. In the same year, T. Cooklev et al. in response to the U. S. NTIA's Notice of Inquiry, presented a permanent cloud-based system-of-systems for spectrum monitoring. The main conclusion is that spectrum monitoring system must be integrated spectrum management and spectrum monitoring on a large scale, but such a system does not currently exist. They describe the interface to the cloud as an importantenabler and propose a solution that allows ontology descriptions to be used for both spectrum management and monitoring[8].

The expected spectrum monitoring system is a real-time and intelligent one, which is a machine-machine infrastructure to acquire and amass monitoring data automatically and make them intuitively available to regulators in real-time, for dynamic, intelligent and efficient spectrum management.

With this aim, we proposed a cloud-based IoT approach to spectrum monitoring withdeploying spectrum sensors and presented a unified cloud computing platform for refined spectrum management. Figure 1 is the system architecture. And Figure 2 is the schematic of cloud computing platform.

The system achieves the integration and unity of cloud, network and terminals. Among them, "cloud" refers to cloud computing and big data infrastructure to provide computing resources, i. e. , cloud computing platform in Figure 1; "network" not only includes 3G, 4G, Internet, VPN, but also extends to IoT, for network bearing, directly providing communication services, i. e. , transport layer; "terminals" means data sources, such as sensors, i. e. , perceptual layer. The perceptual layer is at the most fronted of information collection, esp. an overwhelming flow of data in either structured or unstructured format, which plays a fundamental role in the IoT.

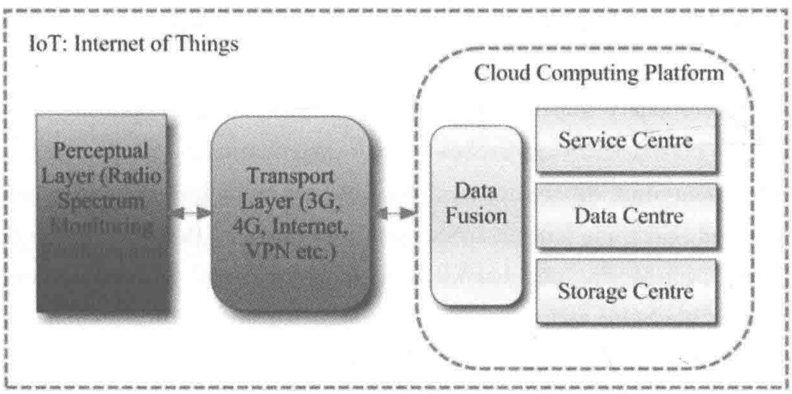


**Fig. 1 The cloud-based IoT architecture**

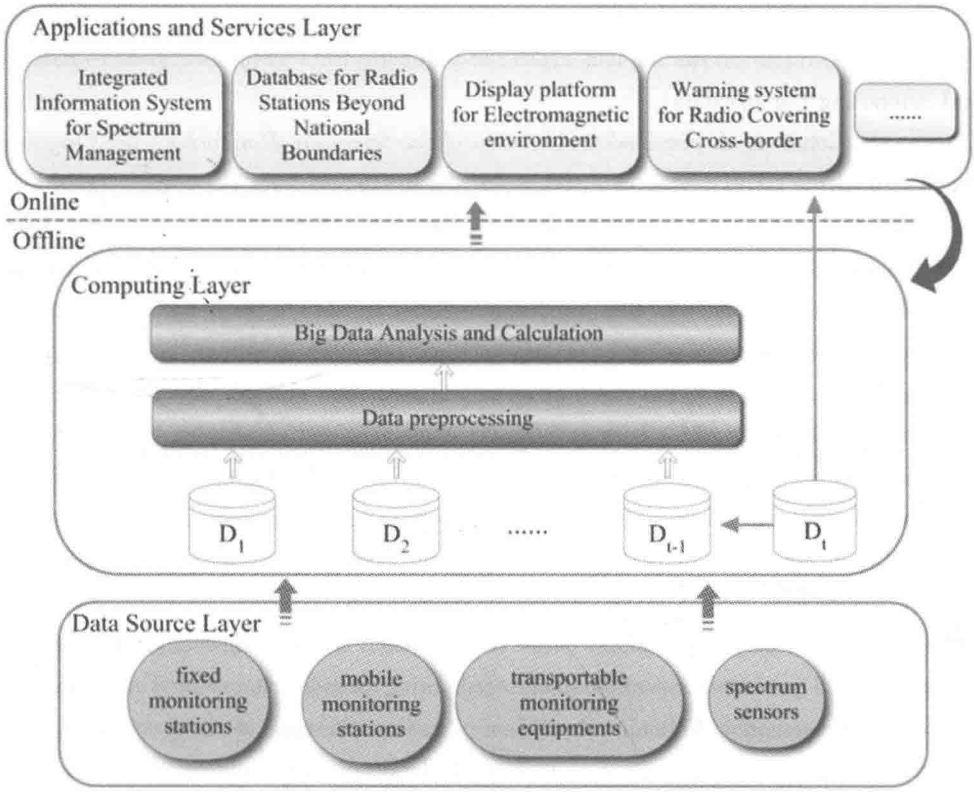


**Fig. 2 Cloud computing platform schematic**

Cloud computing platform realizesthe structured (or unstructured) data extraction and concentration, analyzes and extracts data relations, conducts aggregation, then forms a unified whole data for further display. According to requirements of spectrum regulator, it mines the key data for different services effectively, establishes appropriate statistical analysis models, achieves scientific and advanced management, thus meet radio monitoring and spectrum management demands.

Spectrum sensors are typical simple and inexpensive devices to meet band-specific monitoring requirements with signal processing capabilities. Combined with IoT, sensors deployed with different characteristics are revolutionary substitution to traditional monitoring equipments.

In this regard, we carried out researches on radio monitoring in specific areas based on spectrum sensing, and explored on design approach for antenna minimization of spectrum sensors[11]. A cooperative compressed spectrum sensing model was proposed[12]. Besides, a spectrum monitoring system based on spectrum sensing and LabVIEW to measure illegal broadcasting signals[13-15] was also developed. Sensor hardware and software were designed to detect well-defined system transmissions in specific frequency band(s). What is more, a real-time and intelligent spectrum monitoring prototype system with smart sensors has been built recently in China. Many interesting works have been developed.

## 4 The Prototype System and Early Results

Figure 3 is the prototype system framework. The system consists of spectrum sensing network, communication infrastructure, storage integration, intelligent monitoring data processing and smart visualization. Key parts are spectrum sensing network and big data processing platform (i. e. cloud-based intelligent processing platform).

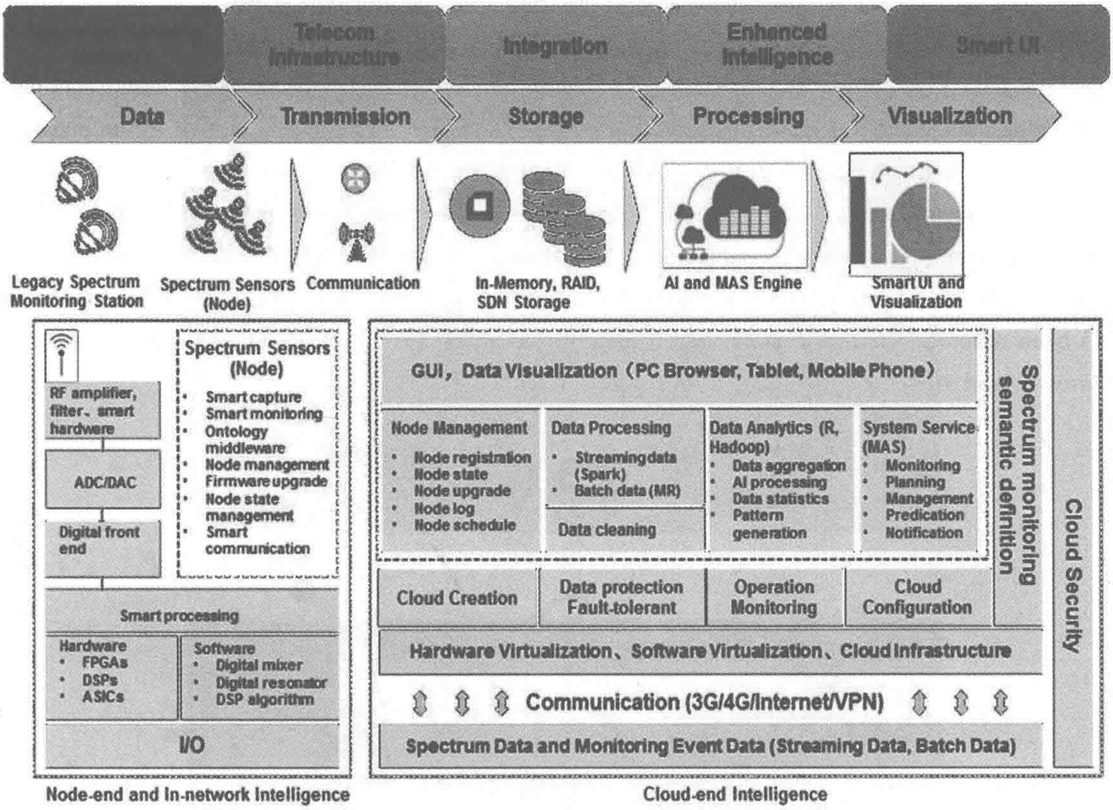


**Fig. 3 The prototype system framework**

Spectrum sensors provide abilities such as automatical spectrum scanning, smart monitoring, intelligent signal processing, data storage, communication and firmware management. Each sensor hardware includes indoor unit and outdoor unit. The indoor unit is made up of signal processing module, routing module and power supply. The outdoor unit consists of spectrum sensing module, two monitoring antennas (one is an omnidirectional wide band antenna with a working frequency range of 20MHz to 6000 MHz, another one is a FM antenna) and surveillance camera, as shown in Figure 4.

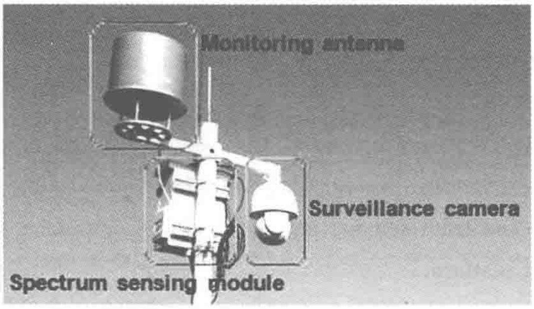


**Fig. 4 The outdoor unit of spectrum sensor in prototype system**

The data processing platform can deal with correlation analysis of spectrum, radio stations, monitoring data and other kinds of data acquired, so as to provide technical support to the management of radio frequency and stations and related foreign affairs.

We deployed 5 smart sensors within VPN in Hekou Yao Autonomous County of Honghe, bordering Vietnam. And arranged a data center, comprising the server and related network equipments, as part of the big data processing platform. Our prototype system topology is shown in Figure 5. It has been running steadily for more than 6 months, as well as intelligently mining many interesting stories behind vast amounts of spectrum monitoring data.

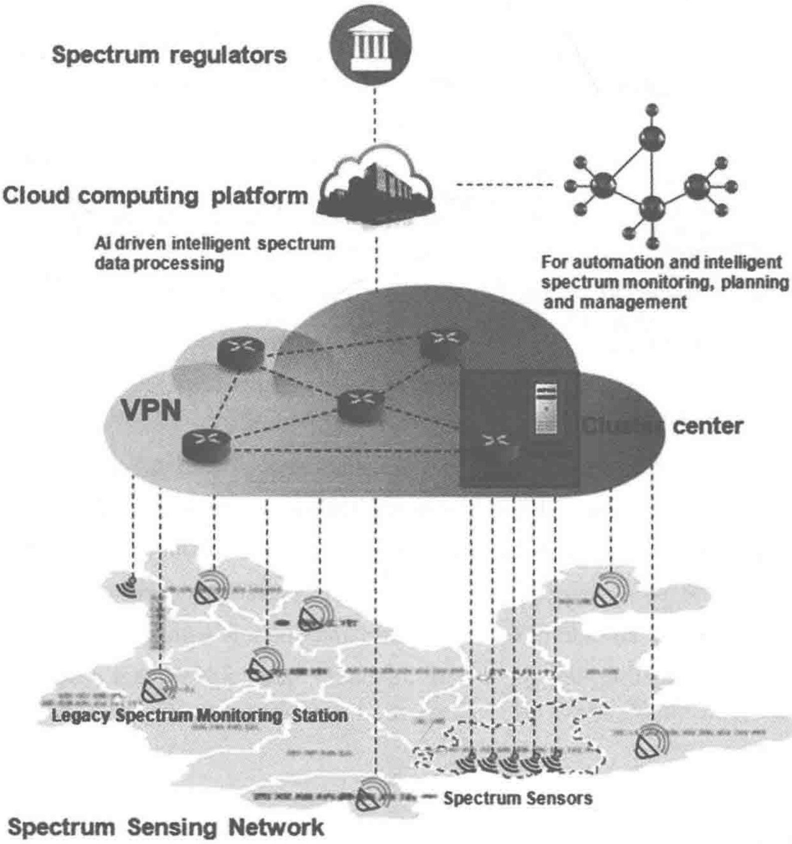


**Fig. 5 The prototype system topology**

According to the Radio Regulation (RR) enacted by ITU, every country should control the use of the radio spectrum on its territory and within its geographical borders. However, the radio wave is propagated in free space and then likely to causing harmful interference to other countries. To simplify matters, international frequency coordination is developed in place, that is a technical and regulatory process which is intended to remove or mitigate radio interference between radio systems from different countries utilizing the same operational frequency, and to ensure rational, equitable, efficient use of the radio spectrum and satellite orbits around the world. There were 12 times sino-vietnamese frequency coordination bilateral talks, and several bilateral agreements were formed.

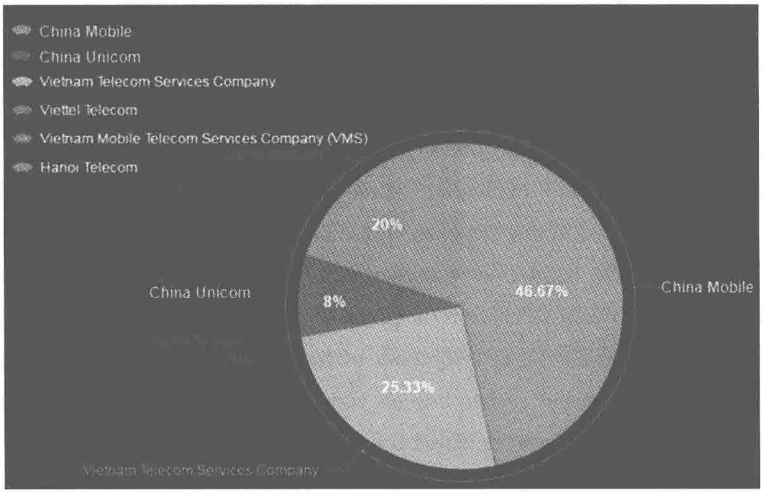


**Fig. 6 A statistical result of the mobile communication signals measured at Hekou**

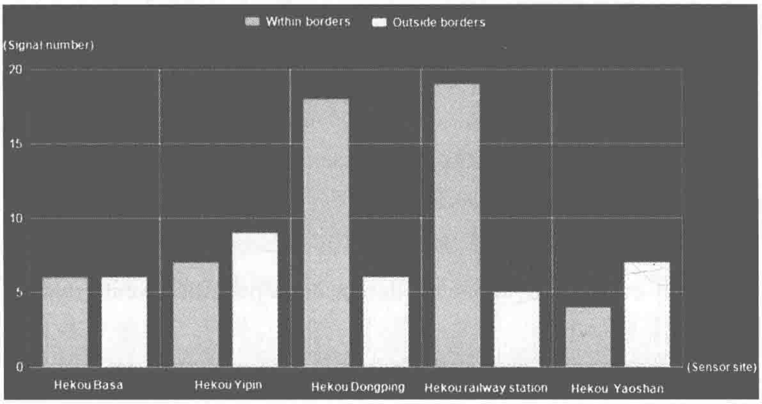


**Fig. 7 A comparison of the total number of mobile commucation signals demodulated by five spectrum sensors deployed at the border town Hekou**

In order to master the initiative in frequency coordination, we especially focused on radio-frequency cross-border coverage measurement in prototype system design. We divided 20MHz to 3000MHz frequency band into several sub-bands, on the basis of 42 kinds of radio services defined in the RR. Combined with monitoring data from spectrum sensors, we obtained intuitive spectrum occupancy of certain radio service between our country and the neighbouring country. Taking the