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Research Article

Development of Wireless Transmission System for Microseismicity in Complex Mountainous Area

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A large amount of data would be generated during the process of microseismic monitoring, and data transmission with the cable has some shortcomings such as poor anti-interference, time-consuming, laborious, high cost, and low construction efficiency. On the other hand, the influence of signal diffraction and the multipath effect will greatly cut down the energy of the signal during the wireless transmission in the complex mountainous area. The wireless transmission system based on Wi-Fi is designed in this paper, which includes the base station and data transceiver. The maximum distance and transmission rate at point-to-point communication of the base station are up to 1000 m and 150 Mbps, respectively, and it provides the communication backbone line for the network. The data transceiver adopts the network protocol based on Ad Hoc, and the transmission distance is up to 200 m at the condition of complex topography and lush mountains. We have applied the system to in-site microseismic monitoring with 28 geophones of the coalbed methane fracturing in South Chongqing. It achieved a good performance with a transmission rate of 1.2 Mbps, a time delay of 1.95 ms, and a signal strength of up to −52.3 dBm for real-time data transmission in the field. The results show that the system has the advantages of low BER, fast transmission speed, long communication distance, and stable and safety hardware and has a great value for more applications of microseismicity in complex topography.

1. Introduction

Microseismicity is the earthquake with a small magnitude induced by the rock failure originated in the change of stress field of underground rock [1]. The events directly are related to the mechanism of rock fracturing at the action of internal and external driving forces. Source parameters, geometric size, and the extension direction of the crack can be predicted on temporal and spatial scale. It has been widely used in unconventional oil and gas fracture monitoring and evaluation [2–4], earthquakes induced by hydraulic fracturing [5–7], mining safety monitoring [8–10], and early warning and prediction of landslides [11–13].

With the improvement of the sampling rate, a large amount of data would be generated during the process of microseismic monitoring. The transmission with cable has some shortcomings such as poor anti-interference, time-consuming, laborious, high cost, and low construction efficiency. As the development of wireless local area network (WLAN) transmission technology, such as Wi-Fi, ZigBee, LoRa, and Bluetooth, it has brought the progress of microseismic data transmission technology in real-time.

Remote, wireless network of seismic sensor stations was achieved for microseismic monitoring. The seismic information is received by a control center station and displayed and analyzed [14]. Zigbee wireless network communication technique is used for wireless data collection of seismic wave detection sensor. Meanwhile, GPRS wireless packet switching technique is used to complete remote data transmission [15]. Remote wireless module, Ad Hoc technology, and AODV (Ad hoc on-demand distance vector) wireless routing protocol are used to complete multihop data forwarding in the case of no other infrastructure [16]. WSNs (wireless sensor networks) based on compression perception is applied to the system design of the source location node, which includes acquisition, storage, and wireless transmission for microseismicity [17]. Weak signal acquisition, wireless communication, and database management are implemented by the optimal layout of a borehole-surface monitoring system [18]. A routine high-resolution microseismic monitoring system was installed in an opencast coal mine to investigate the impact of induced seismicity on the slope failures in real time [19]. The methodology related to data acquisition, analysis, and interpretation from microseismic monitoring was used to determine possible fault locations [20]. Combining a load-balancing scheme with a high-throughput polling mechanism in WLANs, the system allows all the seismographs to associate with the available APs and keeps load balance among the APs [21].

A set of high-precision distributed wireless microseismic acquisition stations was developed by Sun et al. [22], including the acquisition circuit, main control circuit, and other hardware circuits. Advanced acquisition systems are integrated into the ARMs (advanced RISC machines) of the main control board, and Wi-Fi technology was used to achieve wireless data communication [23]. Hardware was developed to address the wireless microseismic acquisition stations and deliver monitoring software based on the Android platform [24]. Microseismic sensors are integrated into the toe of the SMART geotechnical instruments with the MineHop mesh network from Mine Design Technologies (MDTs), which will allow mines to drill one hole to satisfy the requirements of microseismic and traditional geotechnical monitoring [25]. Seismic signals processing system (SSPS) is an embedded computer system that receives real-time waveform data from Sensor Interface & Signals Acquisition (SISA). The SSPS is processed real-time Short-Time-Average through Long-Time-Average (STA/LTA) [26]. A new wireless seismic sensor network system based on Wi-Fi and existing network resources, especially designed for seismic monitoring of buildings, allows remote control, and real-time monitoring of the recorded signals by any Internet browser [27]. A wireless seismic exploration system using a dual-layer network based on Wi-Fi and LTE is developed for long-distance high-rate seismic data transmission with a high reliability [28]. Internet of Things-based wireless technology is developed to a considerable amount of data created by complex seismic scenarios, with the advantages of long range, low power, and inherent compatibility to cloud storage and computing [29, 30].

Due to the complex topography and lush mountains, there are many difficulties in wireless transmission equipment layout, short transmission distance, fast energy scattering, and obvious multipath effect in Southwest China. In this paper, a wireless transmission system based on Wi-Fi mode is developed for the complex mountainous area, which has the advantages of flexible networking, fast transmission speed, long communication distance, and stable and safety hardware. We have applied the system to in-site microseismic monitoring of the coalbed methane fracturing with 28 geophones in South Chongqing, it achieved a good performance for real-time transmission.

2. Wireless Transmission System Design for Microseismicity

2.1. Microseismic Monitoring Network. The sensors for microseismicity are usually arranged in four ways [31]. Surface monitoring is to collect signals by laying geophones on the ground above the monitoring target area (Figure 1(a)). More than 1000 single-component (1C) geophones are usually inserted into the surface. In recent years, the layout of distributed stations is more and more widely used for microseismicity because of its convenient construction and low cost (Figure 1(b)). The three-component (3C) geophones are buried in several meters underground in order to reduce the interference of environmental noise. The advantages of both are the large observation aperture, accurate location on horizontal positioning, and the conditions of focal mechanism inversion. But it is difficult to distinguish from the ground noise. Microseismic monitoring in a shallow hole (Figure 1(c)) usually adopts the combination observation with multiple shallow holes underground 50 to 300 m. The 3C geophones are placed in each hole to detect the signal. This way can effectively avoid intense environmental noise and improve signal quality. However, it brings out the expensive cost because of multiple boreholes drilling. Microseismic monitoring in borehole (Figure 1(d)) is usually arranged the receivers in one well (commonly deep in several thousand meters) near the monitoring target area. The advantages are the good SNR and accurate location, and it is often used to fracturing monitor for unconventional oil and gas.

2.2. Wireless Transmission System in Complex Mountainous Area. The system adopts WLAN communication technology with the wireless topology of base stations and data transceivers based on Wi-Fi mode, as shown in Figure 2(a). The backbone network is composed of base stations, and the communication access point (AP) is consisted of transceivers. The system adopts an open "plug and play" networking mode, which is conducive to the addition of data acquisition nodes.

Single chain is composed of a sensor, data collector, and wireless transceiver, which are connected with each other through cables. The microseismic signal is collected by the sensors, and the analog signal is converted into the digital signal by the ADC in the data collector and converted it into the wireless signal by the transceiver to meet the network communication protocol. The wireless signal from microseismicity is remotely transmitted to the microseismic processing center to analysis and storage through different base stations, as shown in Figure 2(b).

2.3. Base Station. The wireless base station is the main networking equipment of the transmission system for microseismic data. It provides the communication trunk line

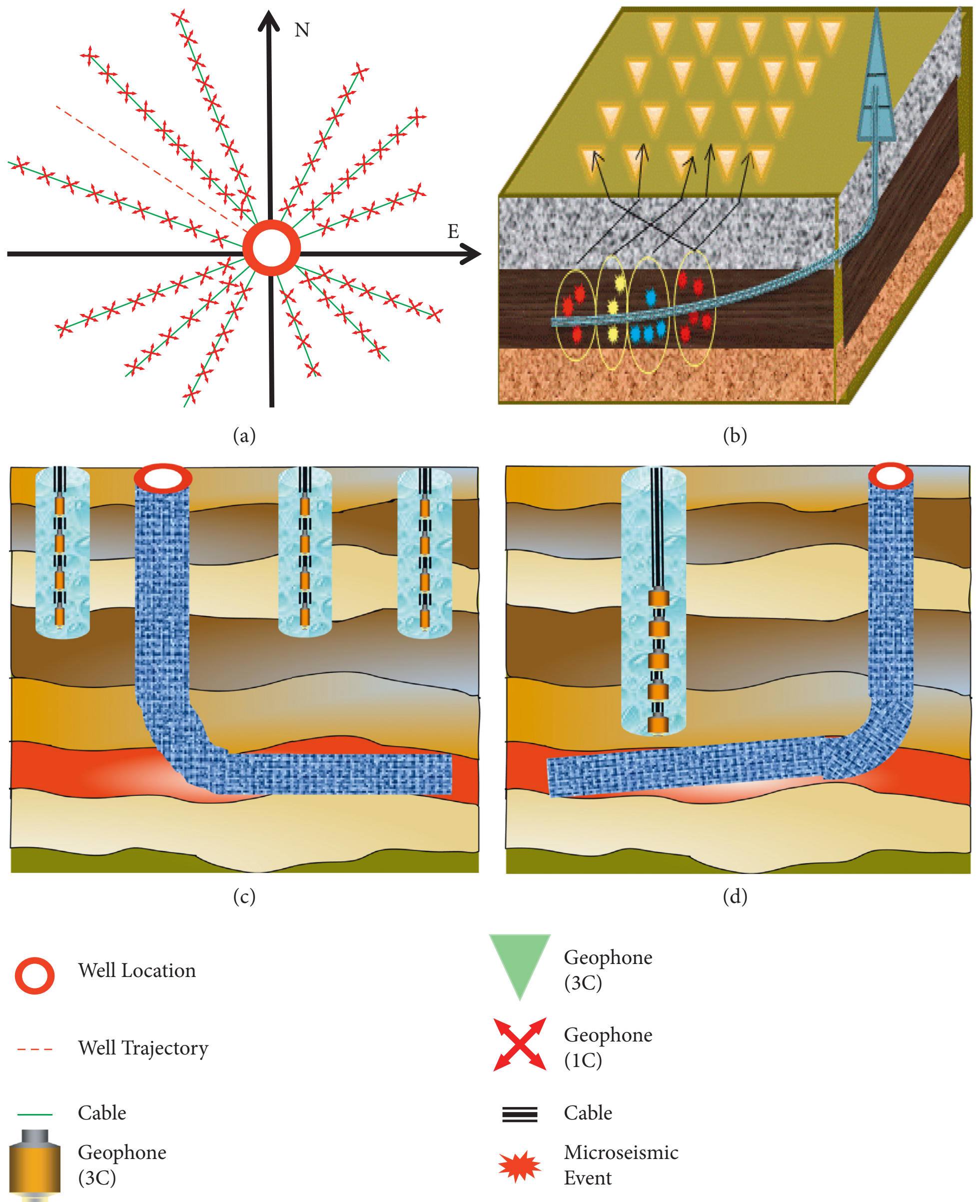


Figure 1: Microseismic monitoring network. (a) Surface array with 1C sensors; (b) distributed station network with 3C sensors; (c) 3C geophones deployed at the various shallow holes; (d) 3C geophones placed in deep boreholes near the fracturing well.

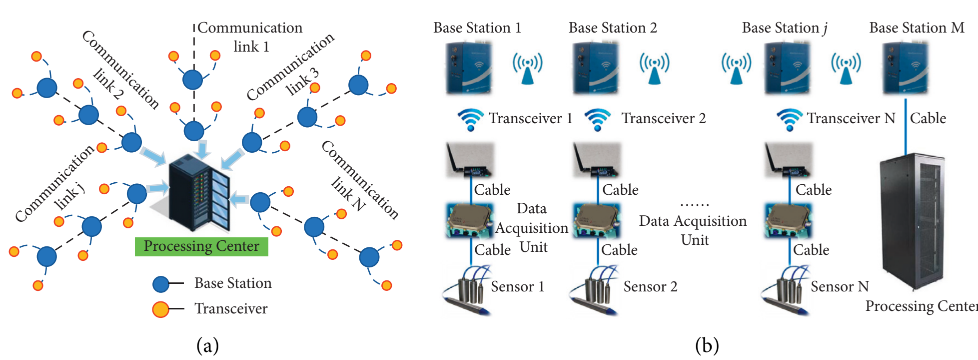
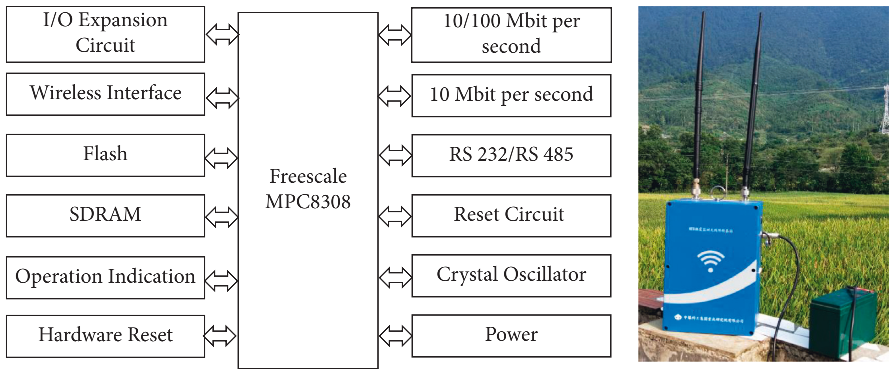


Figure 2: Multilink wireless transmission system architecture. (a) Microseismic data transmission system of multilink cascade; (b) connection diagram of a single link is composed of sensor, data acquisition unit, transceiver, and base station.



(a) (b)

Figure 3: Internal structure diagram of base station (a) and its practicality picture (b).

Table 1: Main parameters of the base station.

Communication protocol	802.11 b/g/n	Serial port mode	RS232/RS485
Frequency range	2.32 GHz to 2.51 GHz	Maximum transmission rate	150 Mbps
Transmission distance	700m @6dBi antenna, flat and no shelter	Maximum access point	255
Encryption type	WEP64/WEP128/TKIP/AES	Security mechanism	WEP/WPA-PSK/WPA2-PSK
Working current	≤600 mA	Working voltage	24.0 V

for the whole network and cascade function in the single trunk link. When the transceiver enters the signal coverage range of the base station, the base station automatically searches for the access node in the same network and allows the security node to automatically join the network after communication handshake authentication.

The base station adopts an embedded system composed of processor, memory, and peripheral chip. The main control chip is Freescale MPC8308 with low power consumption and high integration. The PowerPC e300 core in the MPC8308 is a superscalar processor with the 400 MHz maximum operating frequency and includes the independent on-chip 32K bytes physically addressed cache, on-chip L1 instructions, and memory management units (MMU). The memory includes a 128 MByte unbuffered DDR2 SDRAM discrete devices, 8 MByte NOR flash single-chip memory, 32 Mbit NAND flash memory, and 256 kbit M24256 serial EEPROM [32]. The chip supports dual three-speed (10, 100, 1000 Mbps) ethernet controllers and is mainly applied in wireless base stations, data concentrators, and wireless LAN access points. In this paper, the crystal oscillator with 150 MHz is connected to the processor. The structure diagram of the base station is shown in Figure 3.

In order to meet the transmission requirements of complex mountainous areas, the parameters of the base stations are shown in Table 1. The operating frequency is in the range of Wi-Fi (~2.4 GHz). The maximum distance and transmission rate at point-to-point communication are 1000 m and 150 Mbps, respectively. With the increase of the number of access points (APs) in the network, the transmission rate would be reduced seriously induced by channel congestion due to the limitation of bandwidth. For management consideration, the number of APs should be less than 255 to ensure the real-time transmission of raw data. The maximum power consumption is less than 1.23 W.

The routing protocol is Ad-Hoc on-demand distance vector (AODV) to realize multibroadcast routing. Combination of authentication algorithm and encryption algorithm, the security strategy is worked in WPA-PSK or WPA2-PSK protocol mode. The authentication algorithm adopts an authentication routing protocol based on IEEE 802.11x standard, and the encryption algorithm adopts AES (Advanced Encryption Standard) with 128 bits key and preshared key authentication mode.

2.4. Wireless Data Transceiver. The data transceiver supports three types of network topologies, namely, star, mesh, and cluster tree. In view of the complex environment in the mountainous area, the data transceiver adopts the network protocol based on Ad Hoc, which can minimize the power consumption and cost on the basis of general network layer functions and has the functions of self-organization and self-maintenance. In order to extend the communication distance of the base station as far as possible, any data transceiver will dynamically and automatically join the network as long as there is a network with corresponding ID.

The wireless data transceiver uses MC9S08QG8 as the main control chip, which is connected with the wireless communication module and a 6 dBi antenna to realize the transmission of microseismic monitoring data from the transceiver to the base station. MC9S08QG8 is an 8-bit microcontroller with low power consumption and high performance. It adopts enhanced kernel hcs08, has 8kbit flash and 512 bits ram, 8-bit ADC, and 15 MHz crystal oscillator [33]. The wireless communication module realizes 2.4 GHz Wi-Fi data sending and receiving. The data transmission layer includes two sockets and supports TCP server, TCP client, UDP server, HTTP, and other communication protocols. In addition, new communication

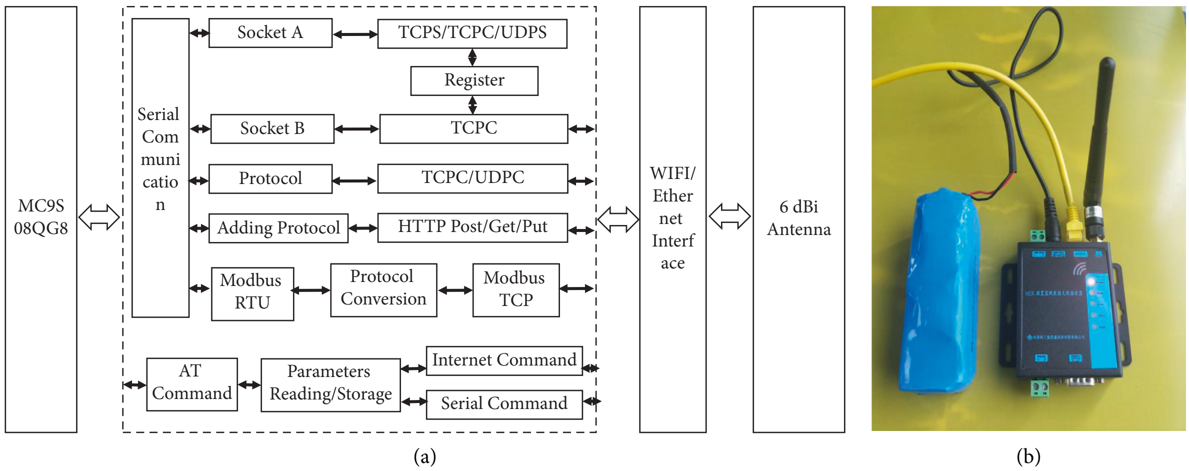


Figure 4: Internal structure diagram of wireless transceiver (a) and its practicality picture (b).

Table 2: Main parameters of the transceiver.

Communication protocol	802.11 b/g/n	Serial port mode	RS232/RS485
Frequency range	2.412 GHz to 2.484 GHz	Baud rate	300 to 460.8 kbps
Transmit power	802.11 b: +19 dBm @11 M bps	Network protocol	TCP, UPD, ARP, DHCPC, DNS, PING
Receiving sensitivity	−89 dBm @11M bps	Working temperatur	−40 to 85°C
Transmission distance	300 m @6 dBi antenna, Flat and no shelter	Security mechanism	WEP/WPA-PSK/WPA2-PSK
Encryption type	WEP64/WEP128/TKIP/AES	Working voltage	5.0 V to 36.0 V

protocols can be added according to user needs. The transceiver also supports Modbus communication protocol, including RTU, ASCII, and TCP. The internal structure diagram of the wireless data transceiver is shown in Figure 4.

The digital signal from the microseismic data collector is transmitted to the wireless communication module through RS 232 or RS 485 serial port and converted it to Modbus TCP communication mode with protocol conversion. It would be sent to the corresponding base station by Wi-Fi interface and antenna and then transmitted to the microseismic data processing center.

The parameters of the data transceiver are shown in Table 2. The baud rate is 300 to 460.8 kbps, and the receiving sensitivity is −89 dBm operating at 11 Mbps. When it is connected with the antenna (transmission gain 6 dBi), the transmission distance is up to 300 m at the condition of the flat and no shelter environment.

3. System Performance Test

3.1. BER (Bit Error Rate) and Time Delay. The digital signal would be distorted by the influence of environmental noise in the transmission process, or the signal voltage is changed due to energy decay. In addition, the signal would be damaged when the hardware works abnormally. Bit error rate (BER) is an index to measure the accuracy of data transmission within a specified time. In this paper, BER is defined as the ratio of error bits to the total number of transmitted bits.

In order to test the stability of the system, the BER of the base station is tested in the field. The base station has been continuously sent the messages to the receiving port for eighteen hours, and the transmission bits is about 2.2×10^8. The error bits are 544, and the BER is 2.47×10^{-6}. The test result shows that the wireless system has the performance of high transmission efficiency and good stability. It is satisfied with the requirements of wireless transmission of microseismic monitoring data. The BER testing results are shown in Table 3.

Table 3: The BER test results.

No.	Sending (bits)	Receiving (bits)	BIT
1	220343392	220342848	$2.47e-6$
2	27200	27200	0
3	26651892	26651883	$3.38e-7$

The wireless transmission system has to meet the requirements of real-time performance and reliability for microseismic data transmission. The system is a hybrid communication mode of multilevel networking, and the tests are carried out under the shelter of trees in the field to check out the time delay. Six base stations with the interval of 400 m are used in the test to form 5 hops (HOP) backbone link with the distance of 2.1 km. The results show that all the time delays of base stations in three HOPs are less than 1 ms, and the delay of the fourth hop increases to 1.85 ms. However, when the number of Hops increases to six, the communication rate decreases significantly and the time delay increases linearly, and the maximum time delay reaches 15 ms, as shown in Figure 5. Therefore, in the complex mountainous environment, the number of base station HOPs is designed to four for the reason of convenience, economy, and effectiveness.

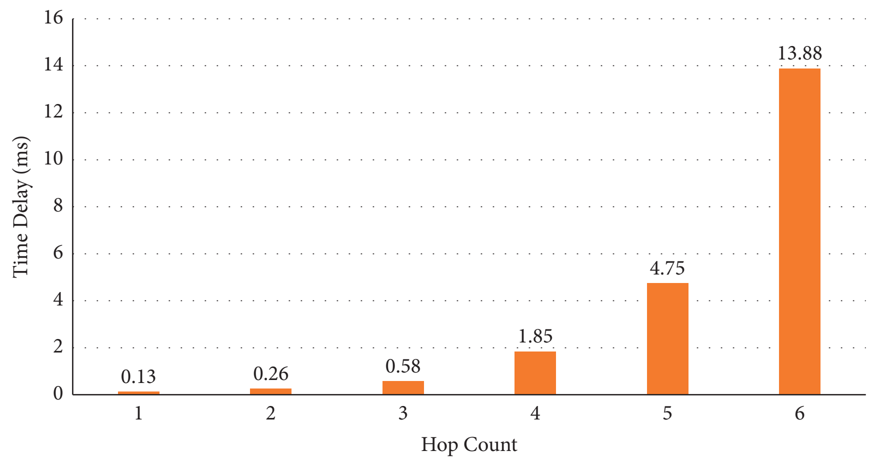


Figure 5: Time delay test for the multilevel cascade of the base station.

Table 4: Signal strength test in LOS and complex mountain environments.

Transmitting power (mW)	Antenna gain (dBi)	Surface topography	Communication distance (m)	Signal strength (dBm)
100	3	Line of sight	10	−32.4
			200	−72.5
			300	−84.5
500		Line of sight	10	−26.3
			200	−65.7
			300	−77.5
1000		Line of sight	10	−22.3
			200	−60.5
			300	−71.2
100	6	Line of sight	10	−31.2
			200	−70.3
			300	−83.7
500		Line of sight	10	−25.9
			200	−65.5
			300	−77.2
1000		Line of sight	10	−21.9
			200	−60.8
			300	−71.1
100	6	Complex mountain region	10	−31.6
			200	−80.2
			300	−94.6
500		Complex mountain region	10	−26.8
			200	−76.8
			300	−86.2
1000		Complex mountain region	10	−22.7
			200	−70.3
			300	−80.2

3.2. Signal Strength. Due to the complex terrain and lush forests in complex mountainous areas, the influence of signal diffraction and multipath effect will greatly cut down the energy of the signal. The transmission frequency is set in the Wi-Fi working frequency range (2.4 GHz), and various communication parameters (transmission power, reception distance, and antenna gain) are changed to provide the optimal communication parameters for the application of an in-site microseismic monitoring system in a complex mountainous environment. The mobile portable wireless monitoring receiver PR100 (R&S company, Germany) is used for testing of signal power strength. It has high sensitivity and scanning speed up to 2.0 GHz/s. The frequency range is 9 kHz to 7.5 GHz. In the scanning process, it can store the intercepted signal at the action of 10 MHz real-time bandwidth, which is suitable for radio reconnaissance, locating interference sources, frequency monitoring, etc.

The test results are shown in Table 4 and Figure 6. Despite the enhancement from the antenna gain, the signal would be greatly attenuated by the shelter of trees and the topographical relief in a complex mountainous area. On the other hand, the signal strength would be improved with

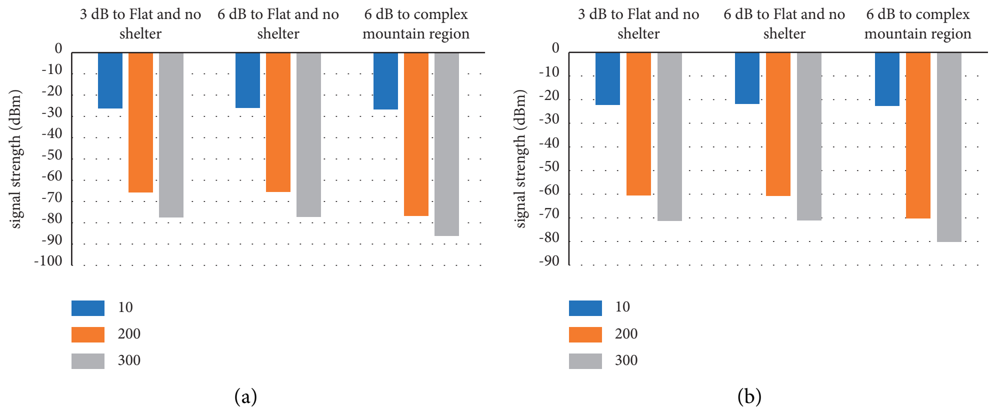


Figure 6: Test for the signal strength with various transmission parameters of the data transceiver, the transmitting power is 0.5 watt (a) and 1 watt (b), respectively.

the transmission power of the source, which is directly related to the effectiveness of data transmission. With the communication distance of 10 m and 200 m, the maximum signal strength is, respectively, −22.7 dBm and −70.3 dBm at the condition of transmission power 1 watt, 6 dBi gain antenna. At the distance of 300 m away from the source, the maximum signal strength is −80.2 dBm, which basically reaches the limit of the signal receiver. Considering the performance and economy of the data transceiver comprehensively, the main communication parameters are adopted 6 dbi gain antenna, transmission power 1 watt, and the transmission distance to the base station is less than 200 m.

3.3. Optimal Throughput Rate of Base Station. The maximum transmission rate of the base station in the backbone link is tested by the method of optimal throughput rate (OTR). The relationship between the number of data transceivers and the OTR of the base station at different distances are achieved at the condition of the complex mountain environment in the field. In general, the OTR test should be operated in a shielded darkroom to reduce the impact from environmental noise. In the process of the field test, the result of the OTR test is affected by the different terrain conditions and noise sources. In order to avoid the impact of multirate transmission on the OTR test of the base stations, the testing environment should not be changed greatly with the increase of the number of base station cascades.

The tests are carried in the field with the shelter from the trees. According to the previous test results, the number of data transceivers is determined to be four, and the distances of the base station are gradually changed as 100 m, 200 m, 400 m, 600 m, and 800 m, respectively. The results are shown in Figure 7. The OTR of the base station increases with the acquisition nodes (data transceivers) when the number of data transceivers in the single link is less than four. The OTR achieves the highest transmission speed when the number of acquisition nodes is four. However, when the number of data transceiver nodes is greater than 4, the OTR begins to decrease with the increase of the acquisition node. The transmission rate of the base station only reaches 1.5 MHz at the condition of the distance of 800 meters and six HOPs. It cannot meet the data transmission requirements when the number is more than 30 microseismic sensors. As a result, in the complex mountainous environment, the number of base station HOPs is designed to four, and the number of the data transceiver is four too.

4. Case Study

4.1. Introduction of the Coalbed Methane (CBM) Well. In order to explore the resources and productivity of coalbed methane in southern Chongqing, the wireless transmission system is applied to microseismic monitoring of two coalbed methane horizontal wells fracturing (Q-H1 and Q-H2) in real-time. The spatial distribution of cracks and the stimulated reservoir volume (SRV) would be predicted to improve the productivity of CBM.

The monitoring area is located in the south of Chongqing, belonging to the passive edge fold thrust belt and Jinfoshan dome fold belt at the upper Yangtze block. It mainly develops multiple fold structures with NE-NNE strike, which is the typical complex geological structure of mountainous areas in Southwest China. The average gas content of the coal seam is 26.14 to 28.18 m^3/t in the monitoring area, and the layer named M8 is highest up to 29.45 m^3/t. The chemical components of the gas are mainly methane, nitrogen, carbon dioxide, and a small amount of heavy hydrocarbon gas. The methane concentration is 89.69~99.36% (the average of 95.74%), which indicates a good industrial value. The wells in the monitoring area are divided into two stages of fracturing. Quartz sand is mainly used as a fracturing proppant, and the fracturing fluid consumption is 1920 m^3 (Q-H1) and 1880 m^3 (Q-H2), respectively. The fracturing belongs to a medium-sized scale compared with the stimulation of coalbed methane reservoirs in China.

4.2. Deployment of the Microseismic Wireless Transmission System

4.2.1. Deployment of the Monitoring Network. According to the topography, distributed microseismic monitoring

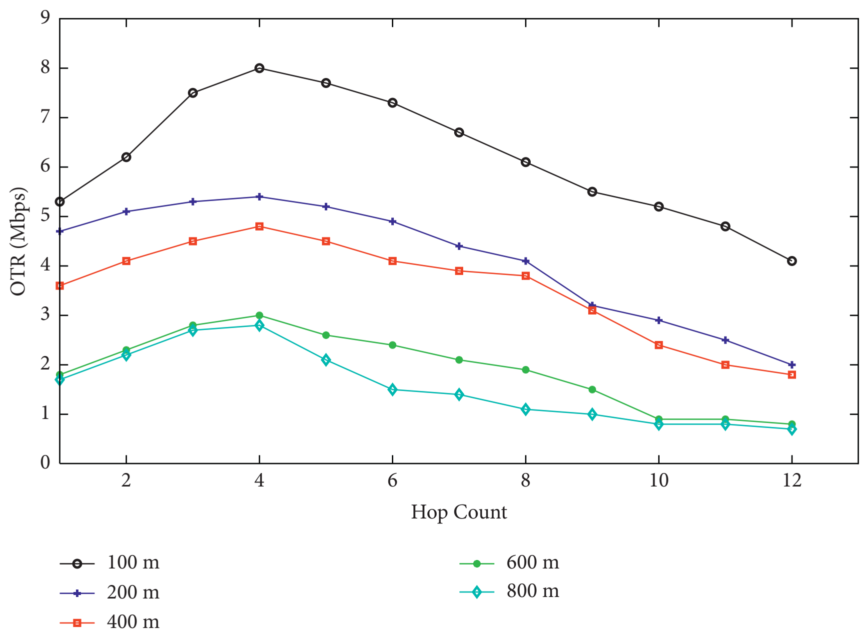
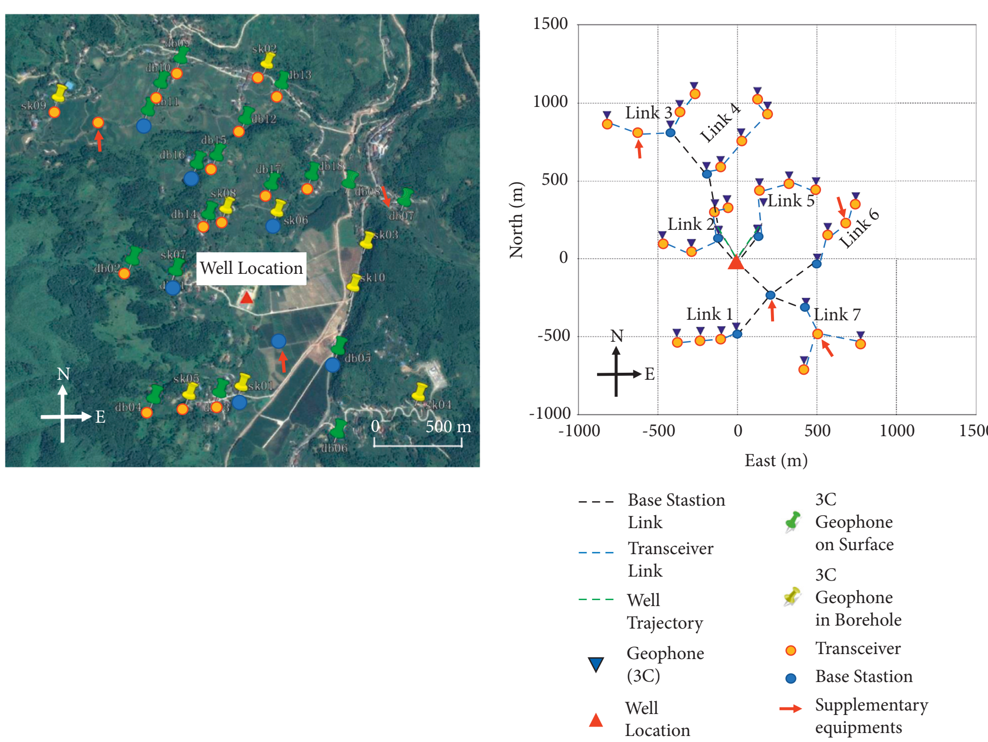


Figure 7: Optimal throughput rate (OTR) test of the base station.



(a) (b)

Figure 8: Deployment of geophones and wireless transmission networks. (a) Microseismic monitoring network; (b) the wireless networks for microseismic data transmission.

system is carried out by a 3C geophone, deployed at the surface, and shallow hole around the monitoring area (Figure 8). Firstly, the geophone in the shallow hole is less affected by environmental noise, and the SNR of raw data is better than the surface. Secondly, the weak signal received from the surface geophone can be calibrated by the high SNR signal detected in the borehole, improving the correct recognition of microseismic events. Consequently, the combination network has the advantages of flexible layout, wide azimuth range and reliable data quality [34].

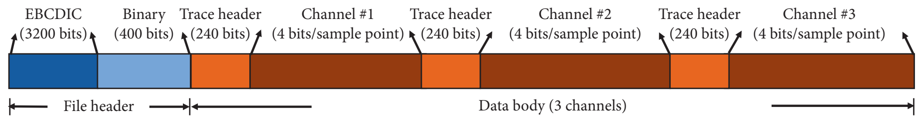


Figure 9: Data body of SEGY format proposed by SEG.

The acquisition system is composed of seismograph, geophones, solar panel, battery, router, and data transceiver, which forms a single transmission link. Nineteen 3C accelerometers (VAS-200) are placed out of the fracturing well with an interval of about 160 m, which is represented by a green pin shape in Figure 8(a). The depth is 0.5 to 1 m, covered by the protection box to decrease the environmental noise. The dynamic frequency range of the sensor is 3 Hz to 1200 Hz, and the sensitivity is better than 220 mV/g. Nine 3C sensors are deployed at the shallow hole with an interval of about 200 m, which is represented by a yellow pin shape in Figure 8(a). The performance is the same as the accelerometers deployed at the surface. The sensor's depth is 15 to 30 m, with cement slurry above to ensure it coupling with the bedrock. The data collector is Sigma 3 plus with 3 channels, high-precision 32-bit AD converter, 12 V voltage power supply, 256 G memory, and the sampling period is from 0.25 to 8 milliseconds triggered by GPS. It supports the transmission model of 4G and Wi-Fi.

4.2.2. Wireless Transmission Network. The microseismic wireless transmission system adopts the hybrid networking mode of star cascade, and a total of 8 base stations and 24 wireless transceivers are arranged to form 7 backbone links, as shown in Figure 8(b). The analog signals collected by the microseismic sensor are converted into digital signals by the data collector and transmitted to the base station through the wireless data transceiver. Then, the signal would be transmitted to the data processing center with the multiple cascaded base stations. According to the testing results, in the complex mountainous environment, the distance from the data transceiver to the base station should be less than 200 m, and the distance of the base station cascade should be less than 400 m. In order to improve the data transmission rate and reduce the time delay, two transceivers are supplemented in link 3 and link 6, respectively, and one transceiver and base station are added in link 7, as indicated by the red arrow. The main communication parameters of the transceiver are adopted 6 dBi gain antenna, the transmission power of 1 watt, and the transmission distance to the base station is less than 200 m. The number of base stations HOPs in a single link are less than 5 data transceivers. The maximum interval between base stations is 400 m, and each trunk line can cascade up to 4 base stations.

The data from the geophone is encapsulated in the standard SEGY format proposed by SEG (Society of exploration geophysicists), which is composed of a file header and data body (Figure 9). The file header includes an EBCDIC header (3200 bits) and binary header (400 bits), which are used to store microseismic description and sampling rate, equipment status, measurement parameters, etc. The data body is composed of trace header (240 bits) and sampling data, the latter is generally floating-point format (4 bits) in IEEE or IBM standard. In the case of the 1000 sps of the sampling rate, each three-component sensor will generate a SEGY file of about 16 kbits packet per second, and 448 kbits for 28 sensors.

On the condition of the sampling rate of 1000 SPS, the data volume generated by 28 sensors is 448 kbps. Besides the routing message, the data transmission throughput of the system in one second needs to reach at least 1 Mbps. Finally, the system has played a good performance with a transmission rate of 1.2 Mbps, a time delay of 1.95 ms, and a signal strength is −52.3 dBm.

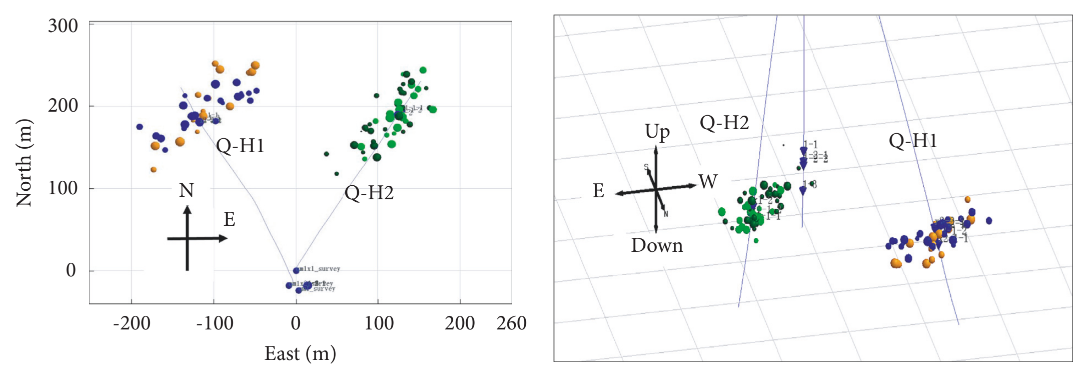
4.3. Performance Comparison with Various Systems. Savazzi and Spagnolini [35] discussed the feasibility of employing Wi-Fi, Wi-Max, Bluetooth, ZigBee, and Ultra-Wideband (UWB) technologies in wireless geophone network. General cable-free land seismic data acquisition and current state-of-the-art wireless seismic data acquisition systems are overviewed by Makama et al. [36] and Yi et al. [37]. Compared with other transmission modes, Wi-Fi has the advantages of wide bandwidth, networking flexibility, reliability, and security in complex application environments. At present, based on IEEE 802.11 protocol, there are several typical wireless systems used in microseismic monitoring, such as UNITE, RT3, and Sigma™.

UNITE system is developed by "Sercel Inc." (Carquefou, Pays de la Loire, France) and consists of a central control station (CCS), remote acquisition units (RAU), and cell access nodes (CAN) [38]. The antennas for Wi-Fi and GPS are set on the top of RAU to improve the data quality through real-time GPS time synchronization. In order to avoid transmission interference, RAU and CAN are operated in the range of 2.4 GHz and 5.8 GHz, respectively. The actual short-distance transmission rate of RAU, based on 802.11b, is normally less than 1 Mbps in outdoor line-of-sight (LOS) environments [28].

RT3 (RealTIME 3) is from the "Wireless Seismic Inc." (Stafford, TX, USA), designed with two-tier radio telemetry architecture and supports over 250,000 cable-less channels [39]. It consists of recording units named Mote, ground Relay Units (GRU) operated in the 2.4 GHz (ISM band), and a central recording system (CRS) worked in the range of 5.6 GHz to 5.8 GHz. The data from the Mote to CRS are transported via GRU communication in real time. The GRU is a full duplex transceiver supported in a line segment, the throughput rate is up to 55 Mbps with the "burst" type. CRS provides three independent views of the spread, including continuous seismic energy and ambient noise levels.

Table 5: Performance comparison with the advanced systems.

Device	Protocol	Technology employed	Dynamic range (dB)	Power consumption	Communication range (m)	Data rate	Manufacturer
RT3	802.11 b/g/n	2.4 GHz ISM band	143	—	<400	<55 Mbps (LOS)	Wireless Seismic, USA
UNITE	802.11a/b/g/n	2.405~2.4835 GHz	128	0.085 w/channel	<1500 (LOS)	<11 Mbps (LOS)	Sercel, France
Sigma TM	802.11 b/g/n	2.4 GHz ISM band	126	0.48 w/channel	<400	—	International Seismic, USA
In the paper	802.11 b/g/n	2.4 GHz	128	0.41w/channel	<400	<11 Mbps	—



(a)

(b)

Figure 10: Microseismic events in inclined well Q-H1 and Q-H2. (a) Vertical view of the events; (b) lateral view of the events. The colors of the sphere represent different fracturing sections, and the size of the sphere represents the local magnitude (M_L) of the events.

Sigma™ is a wireless continuous seismic data acquisition system developed by "International seismic Inc." (Ponca City, Oklahoma, USA). It offers multiple data acquisition and retrieval modes and can be extended to hundreds of channels, including blind data acquisition, control & status nodes, and real-time data transmission within the range of the 2.4 GHz ISM band [40]. When facing different observation conditions and objects, observation strategies can be formed with the corresponding software and observation strategy. Flexible and self-configurable features of Mesh Radio Network (MRN) are allowing Sigma Acquisition Units (SAU) to be deployed in aggressive environments. SAU communicates to maintain the MRN network naturally, providing a redundant wireless connectivity point to reach all units.

The performance of the microseismic wireless transmission system in this paper is compared with the advanced system based on Wi-Fi, as shown in Table 5. For the complex mountainous environment, the communication range and data rate would be significantly attenuated. Due to the different test environments, it is difficult to compare the performance. However, generally, RT3 has the widely dynamic range and the ability of channel expansion (over 250,000 channels) with the flexible layout. UNITE system can be connected with a digital or analog sensor, it is suitable for large-area monitoring, and the power consumption of a single channel is small. Although the data rate of the system in this paper is only up to 11 Mbps at LOS conditions, it can realize the stable transmission of 1.2 Mbps after multihop connection in the complex mountainous environment in Southwest China, which is satisfied with the stable transmission of less than 40 access points. In addition, the maximum communication range can be up to 400 m, and the UNITE and RT3 systems are less than 300 m in the harsh environments.

4.4. The Effect Evaluation of Well Fracturing. With the processes of noise reduction, signal recognition, first break pickup, velocity modeling, and location inversion, 88 effective microseismic events were identified in the fracturing of the two coalbed gas wells (47 events in Q-H1 and 41 events in Q-H2). The local magnitude (M_L) was between −2.13 and 1.24; it indicated that the rock fracturing belongs to a weak event. According to the distribution of the events, the stimulated reservoir volume (SRV) are 65.5×10^4 m^3 and 59.2×10^4 m^3, respectively. The spatial distribution of the events is shown in Figure 10.

Based on the fracturing data and the spatial distribution of the microseismic events, the cracks of the two wells did not connect with each other. However, due to the vertical positioning error caused by low signal-to-noise ratio raw data, some events have the problem of superposition in the vertical direction. In further processing, it is necessary to suppress the influence of noise and establish a more accurately acoustic velocity model of the formation.

5. Conclusions

We have presented a design for the wireless transmission system of microseismic monitoring in a complex mountainous area. It consists of a base station and a data transceiver based on Wi-Fi communication mode. The base station adopts an embedded system composed of processor, memory, and peripheral chip. It provides the communication backbone line for the network and cascade function with the trunk link. The maximum distance and transmission rate at point-to-point communication are 1000 m and 150 Mbps, respectively. The data transceiver adopts the network protocol based on Ad Hoc, which can minimize the power consumption and cost on the basis of general network layer functions. The baud rate is 300 to 460.8 kbps, the receiving sensitivity is −89 dBm operating at 11 Mbps. When it is connected with the antenna (transmission gain 6 dBi), the transmission distance is up to 300 m at the condition of the flat and no shelter environment.

The test results show that the system has the advantages of low BER (2.47×10^{-6}), fast transmission speed (up to 4.8 MHz at the distance of 400 m), long communication distance (about 2000 m), and stable and safety hardware. We have applied the system to in-site microseismic monitoring of the coalbed methane fracturing with 28 geophones in South Chongqing. It achieved a good performance with a transmission rate of 1.2 Mbps, a time delay of 1.95 ms, and a signal strength of up to −52.3 dBm for real-time data transmission in the field. These results indicate that the system has a great value for more applications of microseismicity in complex topography, such as the real time monitoring of landslide, unconventional oil and gas fracturing, and mining safety.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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