Research on Converged Wireless Communication Network Scheme in Nuclear Power Plants

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Abstract. In this paper, the two-way converged wireless communication network (WCN) schemes for three cases in nuclear power plants (NPPs) based on the combiner are investigated. Firstly, the applications of WCN in NPPs are listed, including conventional voice communication and other extension demands. Then the respective advantages and disadvantages of the existing mainstream wireless communication technologies in NPPs are described. Therefore, we need to retain the existing single wireless communication technology and converge other wireless communication technologies via combiners. Secondly, the paper discusses the converged WCN scheme for the cases where the coverage area is small without blind area. Thirdly, the paper describes the converged WCN scheme for the cases where the coverage area is large and feeder installation is unrestricted. Lastly, the paper discusses the converged WCN scheme for the cases where the coverage area is large, but multiple-feeder installation is restricted and signals can be only transmitted by a single feeder. The above three WCN schemes can converge the installed and other wireless communication technologies under different circumstances. Due to the complementation of different wireless communication technologies, various kinds of intelligent business requirements in NPPs can be satisfied and reform cost can also be reduced effectively. Furthermore, it is of great significance to enhance the reliability and performance of wireless communication system in NPPs.

Keywords: Nuclear power plants · Converged wireless communication network · Combiner

1 Introduction

As a valid alternative of wire communication network, wireless communication network (WCN) has been gradually covered in nuclear power plants (NPPs). In order to meet the needs of mobile communication under normal and accident condition of NPPs, especially when wire communication system is not available, WCN can be widely used for making calls and announcing emergency information. With the growing demand of digitization, intelligence and informatization, WCN is being tried in many extensive applications, such as personnel positioning, video surveillance, equipment monitoring, radiation monitoring, fire detection, intelligent operation and maintenance [1].

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At present, some NPPs adopt Personal Handy-phone system (PHS) technology, and some NPPs adopt Multi-carrier Wireless information Local Loop (McwiLL) technology, and some NPPs adopt TD-LTE technology, and some adopt Wi-Fi technology [2]. Each of the existing mainstream wireless communication technologies in NPPs has its own advantages and disadvantages. Wi-Fi technology has higher data transfer rate, lower transmitting power and power dissipation of the base station, but its coverage and mobility are limited. McwiLL and TD-LTE technology can cover larger distance and have better mobility, but transmitting power and power dissipation of the base station are higher. Data transfer rate of TD-LTE technology is higher than that of McwiLL technology. PHS technology has the lowest data transfer rate and has exited the market since December 2010. Many device manufactures have gradually shut down production and industry chain has been interrupted which poses a threat to operation and maintenance of wireless communication system in NPPs. Each single network scheme takes no account of redundancy and fault principle, so it usually has low reliability. Moreover, single network scheme cannot satisfy different types of business requirements. If single PHS or McwiLL technology is applied in NPPs, TD-LTE or Wi-Fi technology will be introduced to meet intelligent business requirements in NPPs which need higher data transfer rate. If single Wi-Fi technology is applied in NPPs, TD-LTE technology is also need to be introduced to meet operation and maintenance requirements in NPPs which need larger coverage and stronger penetrability. Therefore, the two-way converged scheme based on distributed base station is applied in the indoor coverage reforming scheme of wireless communication system in NPPs. That is, one way indoor distribution is shared with other wireless communication technologies (PHS, McwiLL, Wi-Fi), the other way indoor distribution is used for TD-LTE technology. Retaining the existing single wireless communication technology in NPPs, and converging other wireless communication technologies via combiners can not only satisfy different types of business requirements, but also reduce the reform cost effectively without disrupting the existing WCN. The complementation of various wireless communication technologies is of great significance to enhance the performance and reliability of WCN in NPPs.

The rest of this paper is organized as follows. Three converged WCN schemes for different cases according to the coverage area and feeder installation are discussed. Case 1: The coverage area is small and there is no blind area. Case 2: The coverage area is large and feeder installation is unrestricted. Case 3: The coverage area is large and feeder installation is restricted. The converged WCN scheme for case 1 is presented in Sect. 2. The converged WCN scheme for case 2 is presented in Sect. 3. The converged WCN scheme for case 3 is proposed in Sect. 4. Finally, conclusions are drawn in Sect. 5.

2 Converged WCN Scheme for Case 1

For the cases where the coverage area is small without blind area, the converged WCN scheme based on Building Baseband Unit (BBU), Remote Radio Unit (RRU) and single-polarized antenna/dual-polarized antenna is applied in the indoor coverage reform scheme of wireless communication system in NPPs.

BBU is placed in the communication room of nuclear island, and RRU is installed in the weak current equipment room on each floor. BBU and RRU together is the equal of

distributed base station of TD-LTE system. Optical fibers are used in the transmission between BBU and RRU. Optical fibers are used in the trunk line and coaxial cables are used in the branch. There is little attenuation when the signal is transmitted through optical fibers, thus the overall feedline loss can be reduced and has made it far less dependent on the trunk amplifier [3]. BBU and RRU are very flexible in terms of capacity configuration. Scalability is allowed by connecting multiple RRUs and allocating enough capacity to RRUs in a certain area according to the capacity requirements.

The converged WCN scheme for case 1 is shown in Fig. 1. The working frequency of PHS ranges from 1900 MHz to 1920 MHz. The working frequency of McwiLL ranges from 1785 MHz to 1805 MHz. The working frequency of TD-LTE ranges from 2320 MHz to 2370 MHz. The working frequency of Wi-Fi is 2.4 GHz [4]. Several input signals at different frequency bands need to be combined into a single output by combiners which are placed in the communication room of nuclear island. Combiners should have ports of each frequency band and satisfy interference isolation demands among different systems. As Wi-Fi works at the highest frequency band, the link loss is the biggest at the same distances. And Wi-Fi base station has the lowest transmitting power and the most limited coverage range, so Wi-Fi is combined at the end of the branch [5]. The coupler is the device which can extract part of signals in the trunk line. The power splitter is the energy equivalent distribution device which can divide the power signals into equal amounts for different coverage areas. The couplers and power splitters are selected according to some indicators, such as input/output standing wave ratio, insertion loss, input impedance, coupling degree [6]. The working frequency of couplers and power splitters ranges from 1700 MHz to 2500 MHz. RRU or combiners are in turn connected to the coupler, power splitter, and the antenna through coaxial cables.

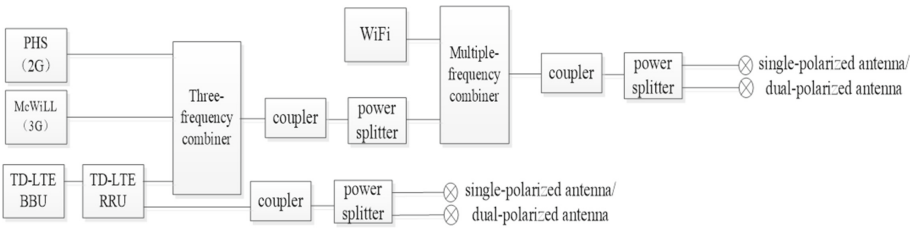

Fig. 1. The converged WCN scheme for case 1

3 Converged WCN Scheme for Case 2

For the cases where the coverage area is large and feeder installation is unrestricted, the converged WCN scheme based on BBU, RRU, dual-feeder MIMO repeater and single-polarized antenna/dual-polarized antenna is employed in the indoor coverage reform scheme of wireless communication system in NPPs.

The converged WCN scheme for case 2 is shown in Fig. 2. Two downlink signals from the sources enter the downlink input ports of the dual-feeder multiple-input multiple-output (MIMO) repeater after passing the couplers. Stray and interference signals are

filtered out by the filters and useful radio frequency signals pass the circulators and are amplified by the trunk amplifiers. To improve the quality of signal coverage, the power of wireless communication terminals can be compensated by the trunk amplifier flexibly and easily. Then the amplified signals pass through the circulators, filters, power splitters in turn and enter the coverage areas. The wireless signals are transmitted by the single-polarized or dual-polarized antenna and thus, the coverage of downlink signals is completed.

The wireless signals from wireless terminals are introduced by the antennas. Interference signals are filtered out by the filters and useful signals are amplified by the low noise amplifiers. The amplified signals go out of the MIMO repeater after passing the circulators and the filters in turn. Finally, the two-way signals pass through the couplers and enter the source receivers and thus, the coverage of uplink signals is completed.

The coverage performance of wireless communication system is also influenced by the selection and installation of antenna. The antenna can be divided into single-polarized antenna and dual-polarized antenna according to different polarization direction. Dual-polarized antenna can be installed in open space such as corridor in NPPs. The performance of dual-polarized antenna decreases significantly compared with single-polarized antenna in independent and closed space such as equipment room in NPPs. So single-polarized antenna is preferred in which case engineering installation is allowed. To ensure MIMO performance, we hope to satisfy two-antenna channel with low correlation requirements by increasing the distance between antennas for the two single-polarized antennas. Try to make sure that the distance between the two single-polarized antennas is more than 1.25 m. The distance should be at least 0.5 m if actual installation space is limited [7]. The working frequency of antenna ranges from 1700 MHz to 2500 MHz.

The power basic unit and the power extension unit are configured to supply power for the dual-feeder MIMO repeater. The monitoring unit is configured to monitor the power state of the dual-feeder repeater and output power of two-way signals remotely. The frequency of monitoring unit can be chosen between 300 MHz and 1000 MHz. However, considering that the working frequency of couplers and power splitters mostly ranges from 800 MHz to 2500 MHz, the frequency of monitoring unit is selected between 800 MHz and 1000 MHz.

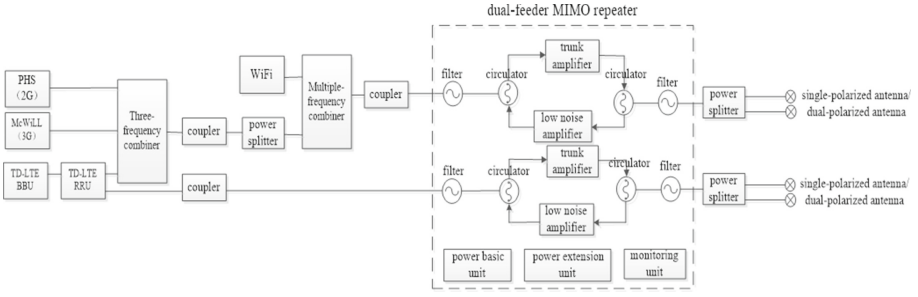

Fig. 2. The converged WCN scheme for case 2

4 Converged WCN Scheme for Case 3

For the cases where the coverage area is large, but multiple-feeder installation is restricted and signals can be only transmitted by a single feeder, the converged WCN scheme based on BBU, RRU, single-feeder MIMO repeater and single-polarized antenna/dual-polarized antenna is employed in the indoor coverage reform scheme of wireless communication system in NPPs. Single-feeder active antenna wireless communication system is realized by means of frequency conversion using a single feeder.

The converged WCN scheme for case 3 is shown in Fig. 3. The single-feeder MIMO repeater includes the proximal module and the remote module, both of which are connected via a single feeder. One proximal module can connect to multiple remote modules. Two downlink signals from the sources enter the downlink input ports of the single-feeder MIMO repeater after passing the couplers. Stray and interference signals are filtered out by the filters in the proximal module. The two-way useful signals pass through the circulators and then are converted into different frequencies at certain interval which do not interfere with each other by the mixers. Then the two-way signals are synthesized to one way signal by the combiner and is amplified by the amplifier. The amplified radio frequency signal passes through the circulator and is transmitted to the remote module through a single main feeder. In the remote module, the signal is firstly separated into two way signals at different frequencies by the splitter after passing the circulator. Then the separated two-way signals pass through the mixers, the amplifiers in turn and are restored back to the two-way signals at original frequencies. Finally, the two-way signals pass through the circulators, the filters, the power splitters in turn and are transmitted by the single-polarized or dual-polarized antenna.

The wireless signals from wireless terminals are introduced by the antennas and are received by the remote module. Stray and interference signals are filtered out by the filters. The two-way useful signals enter the circulators and are synthesized to one way signal by the combiner. The one-way signal is amplified by the amplifier and passes through the circulator and then is transmitted to the proximal module. In the proximal module, the signal firstly passes through the circulator and then is divided into two way signals by the power splitter. The two-way signals go out of the proximal module after passing the circulators and the filters. Finally, the two-way signals are transmitted back to the sources by the couplers and thus, the transmission of uplink signals is completed.

In this scheme, the output signal power of frequency conversion link can be adjusted flexibly so that the power deviation of two-way signals is guaranteed to be within 3dB. This can effectively cut the losses of throughput and system capacity because of the two-way signal power imbalance so that the data transfer rate is the nearest to the maximum uplink and downlink data transfer rate in theory. The proximal module uses independent power supply which includes direct current (DC) power supply and alternating current (AC) power supply. DC power supply can convert 48 V DC into 5 V, 12 V using DC-DC unit in the backplane. AC power supply can convert 220 V AC into 48 V DC using AC-DC unit [8]. The remote module adopts remote power supply via the feeder. 48 V DC signal and radio frequency signals are fed into the same feeder in the proximal module and then is transmitted to the remote module. In the remote module, the power signal is separated from the radio frequency signals by the distributor. Hence, components which allow the DC signal to pass through also need to be selected for the power splitter and

the coupler. This way of remote feeder power supply needs small engineering reform amount without having to increase new feeder.

The proximal module has built-in power basic unit which refers to DC-DC unit and AC-DC unit. The power extension unit which allows the proximal module to connect more remote modules is also configured in the proximal module. Both the proximal module and the remote module have built-in monitoring units which use frequency-shift keying (FSK) modem chip. The monitoring unit can monitor the power state of the modules and output power of two-way signals remotely, and can also control the signal gain.

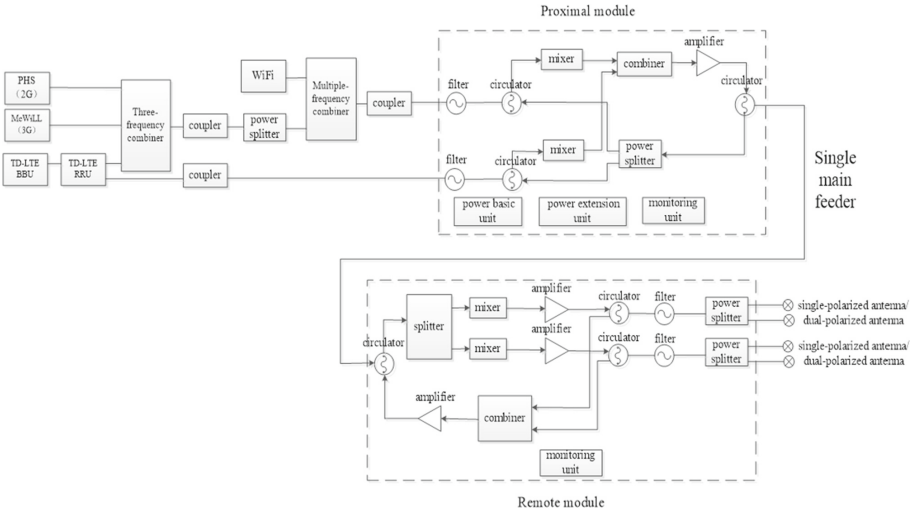

Fig. 3. The converged WCN scheme for case 3

5 Conclusion

This paper presents three converged WCN schemes in NPPs based on the combiner for different cases according to the coverage area and feeder installation. The indoor coverage reforming scheme of wireless communication system in NPPs employs the two-way converged scheme of which one way indoor distribution is shared by PHS, McwiLL and Wi-Fi technology, the other way indoor distribution is used for TD-LTE technology alone. Through the combination of these four wireless communication technologies, various kinds of business requirements in intelligent NPPs are satisfied. It can reduce the reform cost effectively without removing the existing wireless communication technology. It is of benefit to compensate the weakness and take advantage of the strengths of a single wireless communication technology. With the application of the converged WCN scheme, NPPs will develop towards the direction of digitization, informatization and intellectualization.

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