A Study of NI Indoor Wireless Coverage in CPR1000 Projects

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Abstract This article analyses the difference between McWiLL system and paging system in indoor wireless coverage of the nuclear island. It argues the principles and conditions that should be satisfied when doing indoor wireless coverage in the nuclear island. Moreover, how to do design work of NI indoor wireless coverage under these principles and conditions is discussed. Finally, it finishes a proposal of NI indoor wireless coverage using McWiLL system and summarizes the main points of the proposal.

Keywords Nuclear island · Wireless · Indoor coverage

1 Introduction

It is difficult for wireless signal goes through because of many rooms, complex structure and thick wall in the Nuclear Plant. To achieve the purpose of the wireless indoor distribution basic universal coverage, the design is difficult and the program is complicated. Therefore, it's necessary to use electromagnetic theory and radio space propagation theory, combined with the currently identified the technical characteristics of the wireless system for specialized research, design solutions to meet the requirements of the NI of wireless indoor distribution.

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2 Comparison with Reference Nuclear Power Plant

NI wireless indoor distribution of reference nuclear power plant Ling'ao Phase II Project adopts paging system (commonly known as beeper-beeper). The paging system works at the frequency band of 280 MHz. From the relation formula between wavelength and frequency: $\lambda = c/f$ (λ means wavelength, c means velocity of light, and f means frequency), we know that the wireless signal frequency is only 280 MHz. The signal frequency is low, wavelength is long, and diffraction easily occurs according to the physics and electromagnetic field theory. Therefore, indoor distribution by the paging system is still simple, even if NI indoor structure is complex. The coverage problem of the whole NI building will be solved, if several paging transmitters are put in the NI building. But the paging system is lag in technology, shrinking in market and difficult in equipment purchase, so it has been eliminated. New project will not use the paging system again, so the paging system can not be used for indoor distribution.

CPR1000 project NI indoor distribution plans to adopt McWiLL (Multi-Carrier Wireless Information Local Loop) broadband wireless access system. The system can completely replace the paging system in function. Nevertheless, the working frequency of the system reaches is 1800 MHz which is several times as high as that of the former paging system, the wavelength is short, diffraction does not easily occur, so the design difficulty of indoor distribution increases, in the face of daedal indoor environment of NI. McWiLL system is completely different from the paging system, so it can not design indoor distribution with reference to former paging system. It must start all over again, and restudy to obtain a feasible scheme which can meet the operating requirements.

3 Study on Indoor Distribution Scheme

3.1 Design Principles of Indoor Distribution

The selection of signal source for NI indoor distribution adopts connecting base station unit and single circuit in-line tower amplifier, and connecting ceiling antenna by means of connection with power divider or coupler. For the area with larger coverage area and far away from the base station unit, the network signal coverage adopts connecting optical fiber machine by remote at the back of base station unit.

As for the ceiling antenna, main control room and reactor center will not design the ceiling antenna, but other places in the room inside NI, namely all areas that people can touch will be covered with signal. The coverage of special areas such as long and narrow corridor, large-size electrical cabinet room, reactor periphery and reactor top-level maintenance area will adopt special antenna such as directional antenna. But most of rooms will install omnidirectional ceiling antenna to ensure seamless coverage of most of areas in NI.

3.2 Selection of Antenna Power

Table 1 Radiation Oscillation Disturbance Source and Immunity Scope [1] in Sect. 5.3 of GB/T 11684-2003 Electromagnetic Environment Conditions and Testing Procedures for Nuclear Instrumentation stipulate basic requirements of anti-disturbance requirements of nuclear instruments which are used in different places, as shown in the following table.

According to the requirements of Appendix B.1 of the Specifications, the immunity of nuclear instruments for nuclear power plant is 3. From the table, it can be seen that the immunity of wireless signal is 3 V/m (the frequency of McWiLL system is 1800 MHz).

The provisions on immunity requirements in other specifications are shown as follows:

- According to GB 17626.3-2006 Electromagnetic Compatibility—Testing and Measurement Techniques—Radiated, Radio-frequency, Electromagnetic Field Immunity Test [2], the equipment shall meet the test class 3 and test voltage 10 V/m.
- According to the provisions of Sect. 8.4.1.2 of GB 14048.1-2006 Low-voltage [3].

Switchgear and Controlgear—Part 1: General Rules, EMC test requirement for the product is 10 V/m.

Table 1 Radiation oscillation disturbance source and immunity scope unit V/m

Immunity	Disturbance source						
	9 kHz–27 MHz, any source	27 MHz frequency band, CB (citizens band)	Amateur radio, all frequency bands	27–1000 MHz portable, except CB	27–1000 MHz mobile, except CB	27–1000 MHz, except CB, portable, mobile	1000 MHz–40 GHz, all sources
A (controlled)	Consider item by item according to the equipment requirements						
1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2	1	1	1	1	1	1	1
3	3	3	3	3	3	3	3
4	10	10	10	10	10	10	10
5	30	30	30	30	30	30	30
X (harsh)	Consider item by item according to the situation						

– DL/T 478-2001 General Specifications for Static Protection [4], Security and Automatic Equipment stipulates that the ability of the device to withstand electromagnetic interference shall meet the provisions of GB/T 14598.9 Electrical Relays Part 22-3: Electrical Disturbance Test for Measuring Relays and Protection Equipment-Radiated Electromagnetic Field Disturbance Tests [5], namely 10 V/m.

To sum up, in consideration that other specialties fail to raise concrete number requirements for immunity of equipment in NI, from the angle of security, the equipment in NI shall at least meet the immunity requirements of not more than 3 V/m.

$$3\,\text{V/m} = 20\lg 3 \times 10^6 = 129.54\,\text{dBuV} \tag{1}$$

According to the reduction formula:

$$\text{dBm} = \text{dBuB} - 113 \tag{2}$$

$$129.54\,\text{dBuV} = 129.54 - 113 = 16.54\,\text{dBm}.$$

Because the antenna adopts the ceiling installation mode, it is impossibly close to the equipment of other systems in NI, so the power at 1 m away from antenna shall be firstly calculated.

According to indoor propagation model which is suggested by ITU-R Rec.P.1238 [6]:

$$Ls = 20\lg f + 10n\lg d + Le - 28 \tag{3}$$

(f means working frequency, unit MHz; d means path distance, unit m; n means indoor propagation index, a constant within 2.0–3.3, relating to the nature of the building; in consideration of the situation in NI, n = 3; Le means through-wall loss)

$$Le = 37 - 7.9\lg f = 11.28\,\text{dBm} \tag{4}$$

Calculate the attenuation at 1 m away from the antenna:

$$Ls = 20\lg 1800 + 30\lg 1 + 11.28 - 28 = 48.4\,\text{dBm}$$

The transmitting power at entrance of antenna is generally L(0) = 10 dBm, and we can calculate the power at 1 m away from antenna:

$$10 - 48.4 = -38.4\,\text{dBm} < 16.54\,\text{dBm}$$

which is far lower than the value required for resistance to electromagnetic radiation interference. Therefore, we take the transmitting power at entrance of antenna L(0) = 10 dBm, that is to say, 10 mW meets the requirements.

According to one-way communication characteristics of the system in NI, the mobile phone terminal will not transmit signal in NI, so we do not need to consider the interference and influence of signal transmission at mobile terminal on other important devices, but we shall guarantee the transmitting power at entrance of antenna less than 10 mW.

3.3 Confirmation of Signal Coverage Radius of Antenna

The signal coverage radius of antenna is set as r, the power of antenna at r is L(r), and loss is L(r).

In consideration that pipelines, portal frame, equipment cabinet and network structure equipment made of various metal materials in NI will shield and absorb wireless signal, there is possibly the disturbance of other wireless communication signals, so theoretically, there is excess loss of 20 dB, therefore:

$$L(r) = L(0) - Ls(r) - 20\,\text{dBm} \tag{5}$$

According to technical features of McWiLL wireless system, mobile terminal under wireless environment of −90 dBm can meet basic communication requirements. Therefore:

$$L(r) \geq -90\,\text{dBm}$$

$$L(0) - Ls(r) - 20 \geq -90\,\text{dBm}$$

$$10 - (20\lg f + 10n\lg r + Le - 28) - 20 \geq -90$$

$$r \leq 11.3\,\text{m}$$

For appropriate margin, preventing that insufficient signal power at the edge of antenna coverage radius will influence signal reception, we take r = 8–10 (m).

3.4 Field Test

For proving the reliability of data calculated theoretically, we conduct relevant tests in the constructed simulation test environment.

(1) Take the power at entrance of antenna as 10 mW;
(2) Test the strength of cell phone receiving signal within 3–10 m away from antenna by simulation test.

Test data is shown as follows (Table 2):

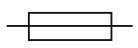
Table 2 Test data

Distance from test point to antenna (m)	The strength of cell phone receiving signal by simulation test (dBm)
3	−56.3 to −58.6
4	−58.4 to −60.2
5	−61.3 to −64.6
6	−62.8 to −65.6
7	−66.6 to −67.8
8	−69.3 to −72.6
9	−73.8 to −75.6
10	−76.8 to −78.2

Thus, it can be seen that, when power of antenna is 10 mW, the coverage radius of 8–10 m can meet basic communication requirements of cell phone terminal −90 dBm.

3.5 *Arrangement of Indoor Distribution Antenna Point Location*

According to the principles of the foregoing discussion, we design the arrangement of antenna point location, as shown in Fig. 1 (take NI 1LX −6.70 m layer as an example):

Among them, □ is the position of signal source, and is generally optical terminal equipment or in-line tower amplifier. Locating place is close to the position of terminal box of other communication subsystems.  is the punching position of cable, and the cable feeder connecting antenna shall traverse wall along the existing cable perforation of other communication subsystems to the greatest extent.

3.6 *Laying of Feeder Cable and Average Power Distribution*

After completion of antenna point location, it is required to lay feeder cable. The principle is to control roughly similar antenna transmitting power at each end, and meet the requirements of less than 10 dBm. This needs to adopt network topology which is composed of coupler or power divider to effectively distribute power. Power divider and coupler of different parameters complete equalization of antenna power under the premise of reasonable route so as to guarantee standard wireless signal edge field strength of coverage area [7].

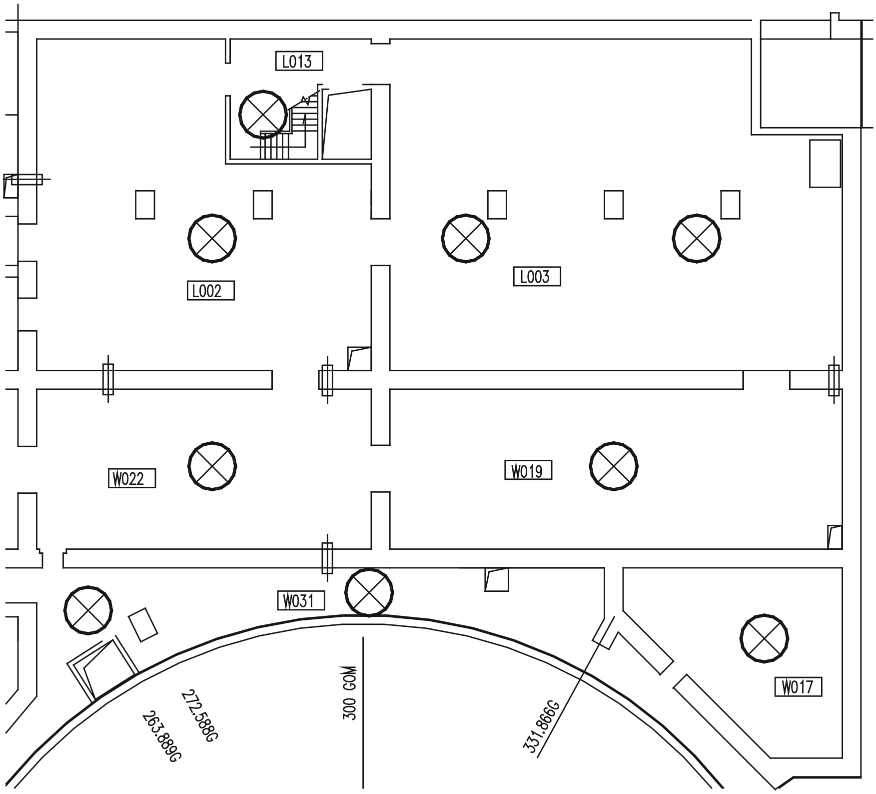


Fig. 1 Arrangement of antenna point location of NI 1LX −6.70 m layer

Table 3 Line loss of feeder every 10 m in each frequency band

Frequency	Feeder	Loss/10 m
1800 MHz	1/2 feeder	1.1
	7/8 feeder	0.7

The parameters of feeder, coupler and power divider are shown as follows (Tables 3 and 4).

The feeder loss is related to its length, so the change in loss arising from the change in feeder length must be considered during design of feeder cable route in order to ensure equalization of antenna power.

3.7 Design Results of Indoor Distribution

Indoor distribution design drawing is basically completed, after completing arrangement of antenna point location and laying of feeder cable as well as adding of equipment coding. The area in NI is too big, so we adopt the subarea design

Table 4 Devices adopted for indoor distribution and loss of each device

Name of device	Power loss value of coupling terminal	Power loss value of straight terminal (exit of power divider)
6 dB coupler	6	1.5
10 dB coupler	10	1
15 dB coupler	15	0.5
20 dB coupler	20	0.5
30 dB coupler	30	0.5
Two-port power divider	/	3.5
Three-port power divider	/	5.5
Four-port power divider	/	7.5

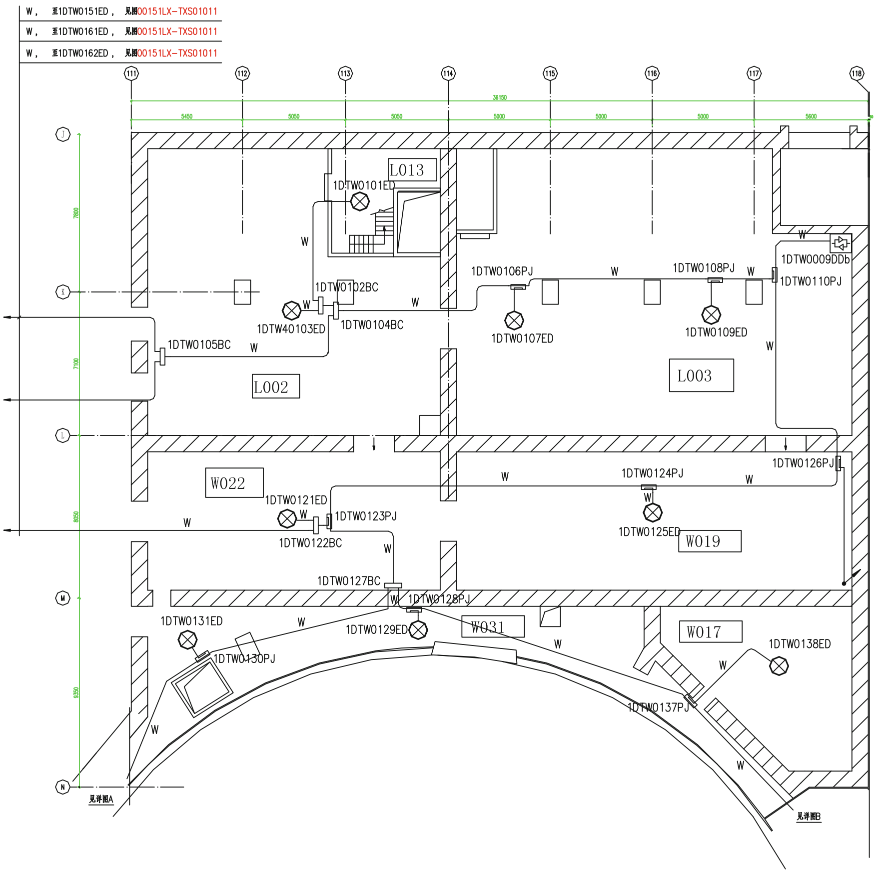


Fig. 2 Wireless communication floor plan for 1LX −6.70 m layer in NI

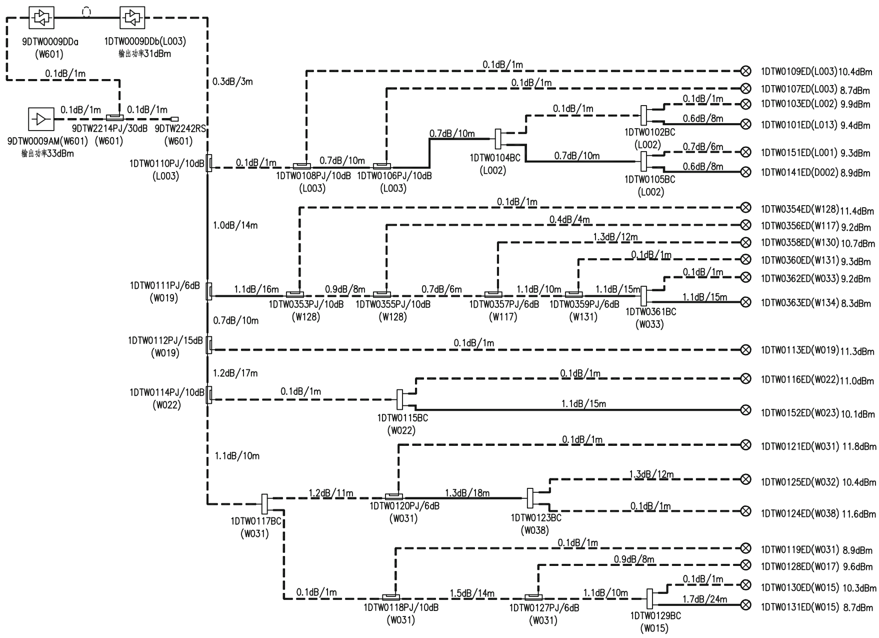


Fig. 3 Wireless communication system chart of NI

method during detailed design. The whole NI building is designed according to 1LX, 9LX, 2LX, 9NX, 1KX, 2KX, 1DX and 2DX subareas respectively. The drawings of different subareas are based on different layers. The following is the drawing for 1LX −6.70 m layer (Figs. 2 and 3).

3.8 Power Supply of Indoor Distribution System

For research and design of indoor distribution in NI, all devices are basically passive devices which do not need special power supply, including coupler, power divider, antenna and feeder. Active devices mainly include base station and optical terminal equipment, UPS power supply specially used for communication system in W601 communication equipment room provides the power to them so as to ensure the power supply reliability of the system, and avoid that the workers in NI fail to receive information timely in case of power failure arising from any accidents.

3.9 Summary of Indoor Distribution Design

- The power at entrance of indoor antenna is controlled at 10 dBm. The antenna or cable may shift in a small range during installation, so we consider a certain margin during design.
- The coverage radius of omnidirectional ceiling antenna is considered as 8–10 m.
- Elevator shaft and staircase adopt directional antenna.
- The adjoining room with the wall thickness of 200 mm or less is equipped with 1 antenna according to the room size and position. Each room with the wall thickness of more than 200 mm is equipped with antenna.
- For avoiding the influence of antenna on the instrument control equipment and other important equipment, the main instrument control equipment room, control room and storage battery room are not equipped with antenna.
- All base stations in NI are set in W601 communication equipment room of +15.5 m layer, appropriate clearance around base station shall be reserved for the convenience of heat dissipation of base station.
- In principle, the optical terminal equipment at each layer shall be installed near terminal box of other subsystems.
- In principle, all cables shall traverse former communication holes (horizontal, vertical). The cables shall not be laid with wind pipe and other metal pipes in parallel. The radius of cable bending (if required) shall meet the requirements of cable technology specifications. Add galvanized steel pipe for cable laying when traversing the hole.
- Coaxial cable entering each diesel factory building shall enter from one place. The diesel factory building does not consider active devices.

4 Conclusions

This research proposes a solution for wireless indoor distribution in NI by adopting McWiLL broadband wireless access system. The scheme avoids the influence on important sensitive devices such as DCS inside NI, effectively solves wireless communication problem inside NI, and also opens new thought for wireless indoor distribution in NI after the paging system is eliminated.

At the present stage, no organizations at home and abroad conduct design and research on wireless communication coverage in NI in combination with McWiLL system and nuclear power plant, which has important innovation significance. The research scheme can be applied to CPR1000 new projects. At present, it has been implemented in Hongyanhe, Ningde and Yang jiang nuclear power plants. Because of flexibility and universality, the appropriately improved scheme is also applicable to nuclear power plant of AP1000 reactor type, enjoying broad development prospect.

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