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WiFi Channel Modeling Method in Industrial Wireless Network Scenarios

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Abstract: As an important support for the intelligent manufacturing system, the industrial Internet is the cornerstone of the comprehensive interconnection of people, machines and things. Compared with other networking technologies, Wi-Fi has advantages such as high rate, low cost and a large number of compatible devices. It is an ideal choice for networking in industrial environments. However, its networking quality mainly depends on signal coverage and the provided throughput. With the rise of mobile edge computing that relies on high-throughput data transmission such as video streams, new challenges have been posed to the networking quality of industrial Wi-Fi with dynamic terminals. In response to the above problems, this paper proposes a channel modeling method for wifi networks in industrial scenarios.

Keywords: WiFi- Industrial private network; Communication network; Channel modeling.

1. Introduction

The core of intelligent manufacturing is interconnection, and the industrial Internet is a key infrastructure in intelligent manufacturing, aiming to achieve comprehensive interconnection among people, machines and things. Through the industrial Internet, various elements such as research and development, design, production, sales, management and service in the industrial chain are universally interconnected, promoting the open flow and deep integration of all kinds of industrial data, thereby accelerating the digitalization, networking and intelligence development of the manufacturing industry, and supporting various emerging business forms and application models emerging under the industrial Internet. It has effectively promoted the process of industrial transformation and upgrading as well as quality improvement and efficiency enhancement [1]. In the process of building the industrial Internet, the choice of networking technology will directly affect the reliability and throughput of the industrial Internet, as well as economic benefits. At present, many industrial Internet networks are organized using Ethernet and fieldbus technologies. These technologies have stable performance and low cost, but lack sufficient flexibility and scalability. With the emergence and popularization of intelligent manufacturing, mobile edge computing applications based on video streams are also constantly emerging, such as video-based autonomous driverless vehicles [2], video security inspection [3], etc. Due to considerations such as cost, power consumption and scalability, industrial edge devices generally do not have strong processing capabilities [4-5]. Therefore, edge devices need to transmit high-definition video streams in real time to the cloud for processing, and after processing in the cloud, return control data for operation. The contradiction between the shortage of wireless channels and the increasing number of network devices as well as the gradually growing amount of data in applications

It has become another major obstacle restricting the development of intelligent manufacturing. The Wi-Fi network operates in the ISM (Industrial Scientific and Medical) frequency band, but the channel resources of the ISM frequency band are very scarce. In China, there are only three non-overlapping 80MHz channels available in the 5GHz ISM frequency band. If adjacent aps use overlapping wireless channels, it will lead to wireless medium conflicts among the terminals associated with the BSS corresponding to the aps, resulting in a decrease in throughput and thereby reducing the networking quality of the industrial Wi-Fi network. In traditional office scenarios, there have been many studies on channel optimization allocation. Through the reasonable allocation of limited channel resources, the insufficient network throughput caused by insufficient channel resources can be alleviated. However, it cannot fundamentally break through the limitations of physical resources and meet the higher requirements for throughput in industrial Wi-Fi networks. The newly added dynamic CCA threshold and BSS staining mechanism in the Wi-Fi 6 protocol can reduce the conflicts between BSS by spatially multiplexing the channel, thereby further improving the throughput and networking quality of the network under the premise of limited channel resources.

2. The Proposed Method

Wi-Fi is a kind of wireless local area network technology that allows devices to communicate wirelessly within a range of several meters to several hundred meters. The IEEE802.11 series standards define the MAC (Medium Access Control) and PHY (Physical Layer) of Wi-Fi. It standardizes the data access methods, encryption methods, wireless rates, working frequencies, etc. of Wi-Fi networks. To cover a wide range of scenarios, Wi-Fi networks can be composed of multiple aps. In order to enable devices to roam among multiple aps without affecting data transmission and the overall performance of the network, the IEEE 802.11 series standards also define a series of protocols for optimizing multi-AP networking. In order to reduce the interference generated among multiple aps, a series of techniques for channel space multiplexing have also been introduced in the latest IEEE802.11ax standard.

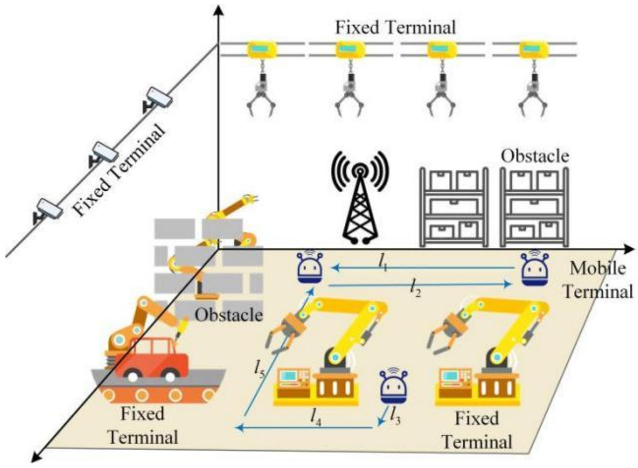

Fig. 1 Schematic diagram of the industrial field network structure

When Wi-Fi signals propagate in the air or pass through obstacles, attenuation occurs. It is necessary to model the propagation channel of Wi-Fi to quantitatively describe the path loss and penetration loss generated during the propagation of Wi-Fi signals, thereby calculating the signal strength that can be obtained at a certain position for the signal emitted by the AP. Path loss in industrial scenarios considers the average value of the signal strength obtained at the receiving end after the Wi-Fi signal has been propagated over a long distance, and large-scale channel models need to be used for characterization. The large-scale channel model widely used in indoor environments is the logarithmic distance attenuation model.

$$S = S(d_0) + 10\gamma \lg \frac{d}{d_0} \tag{1}$$

where, S denotes the signal attenuation that occurs at the terminal after path loss during the process of signal traveling from the base station to the terminal, d is the Euclidean distance of the terminal from the base station, d_0 is the distance between the base station and the reference point, $S(d_0)$ is the actual received signal strength at the reference point, and γ is the path loss coefficient, and the value of this parameter in the industrial scenario is referred to the related work in literature.

Let the signal strength of the i-th AP at the j-th fixed terminal be Pij, then the signal strength obtained by the j-th terminal at the associated AP is:

$$P_j^s = \max_i P_{i,j}^s \tag{2}$$

The coverage signal quality of the fixed terminal can be described using Pjs. For mobile terminals, the associated AP will During the movement process, a switch occurs, and when associated with the same AP, the position of the terminal also affects the signal strength. Therefore, it is necessary Calculate the average signal strength at each point along its moving route respectively to measure its overall signal coverage.

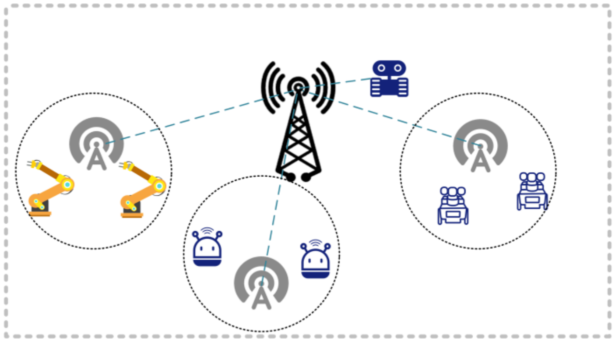

Fig.2 NR coverage area

In this study, we focus on the wifi- multi-RAT dual connectivity scenario. In this architecture, base stations are designated as macro base stations, while NR base stations function as hot spots. All base stations are connected to a central processing unit, which plays a crucial role in coordinating the resource utilization of the base stations, thereby enhancing the overall network efficiency and service quality. Within this scenario, user equipment (UE) with dual connectivity can establish connections with multiple base stations simultaneously within the NR coverage area, meeting the growing demand for high-speed data transmission and diverse services, and expanding the communication capabilities of users in complex network environments. In Figure2, a typical example is presented. UEs UE1, UE2, and UE3 are all equipped with dual connectivity and are within the coverage area of an LTE base station. However, due to differences in geographical location and signal coverage, UE3 can only connect to the LTE base station. This is because it is located beyond the cell coverage radius of any NR base station and cannot receive effective signals from NR base stations, thus relying solely on the LTE base station for communication.

In contrast, UE1 and UE2 are within the cell coverage area of an NR base station. As a result, they have more flexible connection options. They can choose either single connectivity, which involves connecting to either the NR base station or the LTE base station, based on factors such as network load, service type requirements, and signal quality. Alternatively, they can opt for dual connectivity, enabling simultaneous connections to both the NR base station and the LTE base station. This allows them to fully utilize the resources and advantages of both base stations, improving data transmission rates and reducing latency, thereby optimizing overall communication performance. In the specific context of this example, UE1 selects single connectivity, connecting only to the NR base station to leverage its high-speed data transmission capabilities to meet immediate high-bandwidth service demands. UE2, on the other hand, adopts dual connectivity, establishing communication links with both the NR base station and the LTE base station. This approach enables UE2 to take advantage of the wide coverage of the LTE base station and the high performance of the NR base station. It ensures communication continuity and efficiently integrates heterogeneous network resources to address complex and dynamic service scenarios, significantly enhancing the user communication experience. This differentiated connection strategy selection vividly illustrates the flexibility of UEs in allocating network resources based on their specific environment and service requirements within a dual connectivity scenario. It provides strong support for the flexible deployment of 5G networks and personalized user services. It also offers important practical references and theoretical foundations for the future integration and optimization of heterogeneous networks.

3. Condition Tests

In order to verify the optimization effect and operational performance of the algorithm proposed in this chapter, this section implements the algorithm described in the previous text using C++ programming, and uses MATLAB for data processing and chart drawing. Simulation experiments are conducted to verify the coverage effect of each terminal after AP deployment and the operational efficiency of the algorithm.

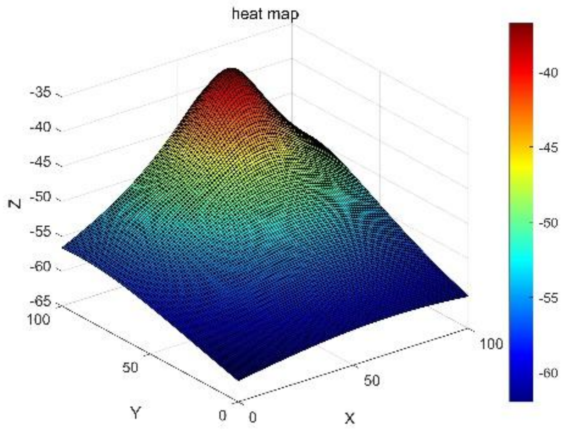

Fig.3 The signal strength contained in the channel

4. Conclusion

Aiming at the AP deployment problem in the complex three-dimensional industrial scene with mobility, the channel model in the industrial scene was established and the AP optimal deployment problem with the overall coverage quality of mobile terminals and fixed terminals as the optimization objective was proposed. Aiming at the deficiency of conventional heuristic algorithms that repeatedly calculate the objective function in each iteration, this paper proposes a channel model solution algorithm suitable for industrial scenarios.

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References

[1] G. EasoLiu Y, Chi C, Zhang Y, et al. Identification and resolution for industrial internet: Architecture and key technology[J]. IEEE Internet of Things Journal, 2022, 9(18):16780-16794.

[2] Singh W, Sengupta J. An efficient algorithm for optimizing base station site selection to cover aconvex square region in cell planning[J]. Wireless personal communications, 2013, 72(2): 823-841.

[3] Zhou X, Yu X, Zhang Y, et al. Trajectory planning and tracking strategy applied to an unmanned ground vehicle in the presence of obstacles[J]. IEEE Transactions on Automation Science and Engineering, 2020, 18(4):1575-1589.

[4] Daniele C, Fabio G, Alessandro N, et al. Optimal territorial resources placement for multipurpose wireless services using genetic algorithms[J]. Wireless Engineering and Technology, 2019, 2, 184-195.

[5] Choi Y S, Kim K S, Kim N. The displacement of base station in mobile communication with genetic approach[J]. EURASIP Journal on Wireless Communications and Networking, 2018:

[6] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.2022.

[7] Yu Y, Lee S. Measurement-based evaluation of video streaming method for remote driving systems[C]. In: 2022 International Conference on Information Networking (ICOIN).IEEE , 2022. 136-139.

[8] E.C Chukwuma. Facility location allocation modelling for bio-energy system in Anambra State of Nigeria: Integration of GIS and location model[J]. Renewable Energy,2019,141.