Construction of Knowledge Graph Based on Conventional Jamming Patterns

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Abstract. Construct a knowledge graph of anti-conventional jamming patterns based on the prior knowledge of conventional jamming patter, Firstly, adopt a manual extraction method to extract the prior information of the conventional jamming patterns and form a structured RDF data set; Then construct the anti-jamming knowledge graph pattern layer ontology from the bottom up and form the classification of anti-jamming decisions: Finally, use Java language to input the constructed data set and ontology classification into Neo4j to form an anti-jamming knowledge graph based on conventional jamming patterns. The result of the expansion of anti-jamming knowledge graph shows that the relationship between the entities of anti-jamming decision-making can be displayed directly by using the knowledge graph, which provides a basis for further implementation of low-complexity anti-jamming decision-making.

Keywords: Conventional jamming pattern · Anti-jamming · Knowledge graph

1 Introduction

With the rapid development of fifth-generation communication, massive wireless connectivity is in great demand. However, due to the openness and broadcast nature of wireless channels, wireless communications are increasingly vulnerable to malicious jamming attacks, where a third-party node injects jamming power into the legitimate users, hindering the legitimate transmission by decreasing the signal-to-interference-plus-noise ratio (SINR) [1]. Therefore, anti-jamming is an essential ability for wireless communications.

The type of jamming attacks can be divided into two categories: natural interference and human jamming [2]. Human jamming can also be divided into two categories: unintentional jamming and malicious jamming. Unintentional jamming generally refers to the jamming of wireless communication system caused by communication, radar, navigation, broadcasting and other wireless equipment itself and its radiation outside the band. In order to interrupt the transmission of specific information, some organizations or individuals release a malicious wireless signal for a specific wireless communication signal, so that the target communication signal could not be received normally, which called intentional jamming. Common human jamming patterns mainly include single tone, multi-tone, narrow band, wide band, linear sweep, periodic pulse, tracking jamming, etc. All the jamming has a serious impact on wireless communication. Therefore, it is necessary to take strong anti-jamming technical measures.

For a long time, the main technical measures of communication anti-jamming include direct spread, frequency hopping, time hopping, UWB and so on. These

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technologies have also been combined with jamming detection/sensing, adaptive anti-jamming, anti-jamming decision-making and other technologies to effectively improve the anti-jamming performance of wireless communication systems. For example, in Literature [3], the frequency adaptive anti-jamming technology based on jamming detection technology was proposed, which effectively improved the ability of wireless communication to avoid fixed jamming. Literature [4] proposes an adaptive frequency-hopping anti-jamming technology based on sweep jamming perception, which can avoid sweep jamming in real time according to sweep frequency law. Literature [5] proposes a method to design the optimal receiver against periodic pulse jamming, which simulates the signal of ranging equipment through the Gaussian mixture model, and drives the parameters of the Gaussian mixture model according to the characteristic properties of the signal to eliminate the periodic pulse jamming caused by the ranging equipment by designing the optimal receiver. Literature [6] proposes an anti-jamming method that uses reinforcement learning to learn the sweep jamming behavior and then obtains the optimal anti-jamming strategy. Literature [7] presents a tracking jamming detection method based on multi-channel detection. All the above put forward corresponding anti-jamming methods for different jamming patterns respectively, but two problems are still unsolved. First, most of the existing literature proposes algorithms for a specific jamming pattern, and it is difficult to provide effective anti-jamming strategies for a variety of different jamming patterns. Second, the lack of common sense reasoning ability, it is difficult to effectively use the prior knowledge of conventional jamming patterns to achieve low complexity real-time anti-jamming.

Knowledge Graph is a branch of artificial intelligence that uses graph model to describe the relationship between knowledge and modeling the relationship between everything in the world, which is of great significance for explaining artificial intelligence [8]. A graph is made up of nodes, which can be entities or abstractions, and edges, which can be properties of entities or relationships between entities. The early concept of knowledge graph comes from Semantic Web, which is the result of the interaction and inheritance of Semantic Web, knowledge representation, ontology, Semantic Web, natural language processing and other related technologies. Since 2012, when Google first used the Knowledge Graph to improve the search experience and improve the quality of search, it has attracted a lot of attention from academia and industry. As a new method of knowledge representation and a new idea of knowledge management, knowledge graph has been widely used in knowledge search, intelligent question-answering, big data analysis, natural language understanding and auxiliary device interconnection.

Therefore, we introduce the knowledge graph into the field of communication anti-jamming to improve the intelligence level of communication anti-jamming from the perspective of knowledge utilization. The main innovation of this paper is that the anti-jamming prior knowledge is represented in the form of knowledge graph, which has the advantages of strong expansibility and low complexity. The structure of this paper is as follows: in the second part, the system model is proposed and eight kinds of conventional jamming patterns and their anti-jamming strategies are briefly introduced. In the third part, the establishment method of anti-jamming knowledge graph of conventional jamming patterns is given. In the fourth part, the general jamming pattern knowledge graph library based on Neo4j and its application are given.

2 System Model

2.1 Anti-jamming Knowledge Graph Architecture

The main objective of the anti-jamming knowledge graph is to store the prior knowledge of anti-jamming so as to realize the low-complexity anti-jamming decision under the conventional jamming pattern. The anti-jamming prior knowledge is mainly stored in the graph database in the form of triples. The construction technical process of anti-jamming knowledge graph is shown in Fig. 1.

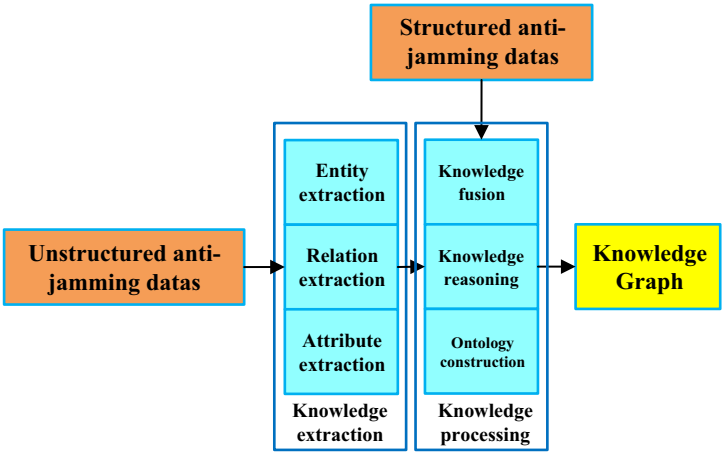

Fig. 1. Construction process of the Graph

The architecture of knowledge graph includes the logical structure of knowledge graph itself and the technology (system) architecture used to construct knowledge graph.

Logical Structure. In terms of logic structure, anti-jamming knowledge graph can be divided into data layer and pattern layer. Knowledge is stored in the form of "entity-relations-entity" triples or "property-value" pairs at these two layers.

The data layer stores facts and instances. The entities of the data layer are specific jamming patterns and information, such as single-tone aiming jamming, jamming attributes, etc. The pattern layer stores concepts, rules, categories, etc., and the entities of the pattern layer are generally abstracts, also known as ontologies, such as the category of jamming patterns and the classification of anti-jamming modes.

Construction Method. This paper adopts the bottom-up approach to construct the atlas: with the help of certain technical means, entities are extracted from some open linked data, resource patterns are extracted from publicly collected data, and new patterns with high confidence are selected, which are manually reviewed and added to the knowledge base, and then the top-level ontology pattern is constructed.

The advantage of this method is that it can generalize ontology according to data pattern type and determine framework classification upward in the absence of authoritative ontology data support, which is in line with the cognitive process of knowledge.

2.2 Anti-jamming Strategies of Conventional Jamming Patterns

Conventional jamming patterns mainly refer to eight common man-made intentional jamming, such as single-tone aiming jamming, multi-tone (comb)jamming, wide-band blocking jamming, partial band jamming, sweep jamming, periodic pulse jamming, tracking jamming, high-speed collision jamming, etc. The definitions and expressions of these jamming are shown in Literature [9]. The main attributes and anti-jamming strategies of conventional jamming are as follows:

Table 1. Main attributes of different jamming and their anti-jamming strategies

Number	Jamming pattern	Main attributes of jamming	Anti-jamming strategies
1	Single-tone aiming jamming	Start-end frequency, bandwidth	Adaptive frequency change, power adaptation
2	Partial band jamming	Center frequency, bandwidth, power, start frequency, end frequency	Adaptive frequency change, power adaptation
3	Multi-tone jamming	Frequency point or channel	Adaptive frequency change, power adaptation
4	High-speed collision jamming	Total bandwidth, instantaneous power, start frequency, end frequency	Adaptive frequency change, power adaptation
5	Wide-band blocking jamming	Total bandwidth, total power, center frequency	Jamming bandwidth is not beyond the working bandwidth of wireless communication system: adaptive frequency change and power adaptation
			Jamming bandwidth exceeds the operating bandwidth but with less power: modulation, channel coding, and power adaptation
			Jamming bandwidth exceeds the working bandwidth and with larger power: blind source signal processing or replacing the working frequency band
6	Sweep jamming	Start frequency, end frequency, instantaneous power, instantaneous bandwidth, sweep cycle	Adaptive frequency hopping, power adaptive
7	Periodic pulse jamming	Center frequency, bandwidth, cycle, duty cycle, instantaneous power	Adaptive time hopping, power adaptive
8	Tracking jamming	Bandwidth, instantaneous power, tracking rate	Accelerating frequency hopping or adaptively changing the working frequency band

3 Establishment of Communication Anti-jamming Knowledge Graph of Conventional Jamming Patterns

3.1 The Construction Process of Anti-jamming Knowledge Graph of Conventional Jamming Patterns

Referencing literature [10], according to the logical framework of the anti-jamming knowledge graph, the construction process of the anti-jamming knowledge graph proposed in this paper mainly consists of the following steps: (1) Extract the entity knowledge of the jamming pattern from the existing conventional jamming pattern data; (2) The extracted knowledge is processed and transformed into structured RDF data form through knowledge reasoning; (3) The ontology is constructed upward according to the extracted structured triad data; (4) Entity and ontology are respectively corresponding to data layer and pattern layer to form anti-jamming knowledge graph.

3.2 Construction of Anti-jamming Knowledge Graph

Knowledge Extraction. The main purpose of anti-jamming knowledge graph construction is to reduce the complexity of decision-making, so the key information is anti-jamming decision-making and the information or characteristics of jamming patterns related to it. The data layer knowledge is extracted from the above table on this basis. Since the scale of the data is small: there are only 8 kinds of conventional jamming patterns, the entity extraction can be manually carried out directly based on experience.

Entity Extraction. Entity extraction is to identify the named entity from the data and indicate the category. In this paper, entity extraction is carried out in Table 1.

Entities can be extracted by jamming types: single-tone aiming jamming, multi-tone (comb) jamming, wide-band blocking jamming, partial frequency band jamming, linear sweep jamming, periodic pulse jamming, tracking jamming and high-speed collision jamming.

Entities can be extracted by anti-jamming strategy: adaptive frequency change, power adaptation, adaptive frequency hopping, adaptive time hopping and accelerating frequency hopping rate.

"Main attributes" in Table 1 belong to the scope of attributes and will be researched in attribute extraction.

Relation Extraction. Relation extraction mainly obtains semantic relations between entities through modeling text data.

The entity relationship of the data layer as shown in Table 1 mainly reflect in the relationship between the entity of the interference pattern and the entity of the anti-interference strategy. "Entity-relationship-entity" can be extracted as: "single-tone aiming jamming—anti-jamming strategy—adaptive frequency change + power adaptation", and the remaining entities can be extracted in the same way.

Attribute Extraction. The purpose of attribute extraction is to construct attribute list and enrich entity connotation.

The corresponding properties of the jamming pattern entities can be extracted from the data in Table 1. "Entity—Attribute—Value" can be extracted as: "Single tone aiming jamming—main attribute—starting and stopping frequency of interference + bandwidth", and the remaining attributes are as above.

Knowledge Reasoning. Knowledge reasoning is based on the existing ontology relations and establishes new relations through reasoning, which can expand and enrich the knowledge stored in the graph, and excavate new knowledge from the existing knowledge, which is the key link in the construction of anti-jamming knowledge graph.

Taking the entity relationship as an example, "single-tone aiming jamming—anti-jamming strategy—adaptive frequency change + power adaptation", this relationship of data layer is relatively single, from which we need to reason and dig out new knowledge and relationship:

First of all, consider the relationship between the two entities of "single-tone aiming interference" and "adaptive frequency modulation". According to the classification of basic anti-jamming modes in literature [11], communication jamming patterns can be divided into aiming jamming, arresting jamming and multi-target jamming. Among them, aiming jamming is used to interfere with a particular channel communication. Then single-tone aiming jamming belongs to the category of aiming jamming, whose principle is that the characteristics of the jamming spectrum are similar to the signal spectrum, and the position and occurrence time on the frequency axis are completely or approximately coincident. Its anti-jamming strategy "adaptive frequency change" is to change the communication frequency to no jamming or weak jamming frequency.

The process of inferring and excavating the deep relationship between the two entities: single-tone aiming interference refers to targeting the jamming signal at the frequency of the communication signal; Adaptive frequency modification is to make the communication signal avoid the jamming frequency -> if still targeted by jamming signal, the signal is still jamming -> Adaptive frequency modification can be successful only if there is a frequency that is not targeted -> Single-tone aiming jamming targets only a specific frequency, there are other frequencies that are not targeted -> Adaptive frequency change can resist single-tone aiming interference.

Finally, a new attribute is excavated. Since the goal of anti-jamming knowledge graph is to make anti-jamming decisions, this attribute is described from the perspective of anti-jamming parties. It is summarized as "frequency gap exists", and the corresponding opposite attribute is "no frequency gap" due to the opposite nature of the attribute. Then the relation group corresponding to the two entities is obtained: adaptive frequency change - application situation - frequency gap exists; Adaptive frequency change - not applicable - no frequency gap; Single-tone aiming jamming - pattern features - frequency gap exists.

By inferring other deep relationships, a set of such relationships is obtained: adaptive frequency hopping - applicability - frequency gap exists; Adaptive frequency hopping - not applicable - no frequency gap; Sweep jamming - pattern feature - no frequency gaps, which conflicts with the data in Table 1, so further study of the attribute "frequency gap exists" is required. Comparing the frequency characteristics of single-tone aiming jamming and sweep jamming, it can be seen that the frequency of single-tone aiming jamming does not change in the whole time period, while the

frequency of sweep jamming changes constantly in the whole time period, so the frequency gap of single-tone aiming jamming is fixed, and the frequency gap of sweep jamming does not exist for the whole time period. The basic principle of adaptive frequency hopping is basically similar to that of adaptive frequency changing. The difference is that frequency changing is completed at a time point, and the frequency will not change after completion. Frequency hopping changes the frequency at each frequency hopping instantaneous. Therefore, attributes can be further divided into full time and transient cases. Under instantaneous observation, sweep jamming can be regarded as a narrow-band jamming with the same pattern characteristics as single-tone aiming jamming, so the attribute of "frequency gap exists" would be changed to "instantaneous frequency gap exists".

The relation group corresponding to sweep jamming is changed to: adaptive frequency hopping - application situation - instantaneous frequency gap exists; Adaptive frequency hopping - not applicable - instantaneous no frequency gap; Sweep jamming - pattern characteristics - instantaneous frequency gap exists.

The single-tone aiming jamming relation group was changed to: adaptive frequency change - applicable situation - full time frequency gap exists; Adaptive frequency change - not applicable - no full time frequency gap; Single-tone aiming jamming - pattern features - full time frequency gap exists. Both of these relationship groups were established.

Finally, the entity set of the anti-jamming knowledge graph of the conventional jamming pattern is obtained.

Ontology Construction. Ontology construction abstracts entities to construct ontology. Ontology construction can adopt either manual construction or data-driven construction. Since the scale of conventional jamming pattern data is small, manual construction is adopted in this paper.

The construction process of anti-jamming knowledge graph ontology is to abstract the entity network of the data layer and construct the pattern layer from the data layer.

Construction Principles. Completeness: In order to make full use of knowledge graph to express knowledge, the classification of schema graph should be able to point to all entities in the data layer according to the path of corresponding classification.

Uniqueness: In order to avoid ambiguity and unclear relationship representation, the classification path of the schema diagram should point to the unique corresponding entity, so as to avoid the problem of multiple paths with the same result.

Selection of Classification Mode. The first step classification of anti-jamming knowledge graph data layer can be classified according to the classification mode of jamming system [11], which can be divided into aiming jamming, arresting jamming and multi-target jamming. However, this classification method cannot cover all jamming patterns. For example, sweep jamming can be classified as instantaneous aiming jamming, and can also be classified as blocking jamming within a sweep period, which cannot meet the uniqueness requirement.

The jamming pattern can also be divided into frequency domain jamming, power domain jamming and time domain jamming according to the composition elements of the jamming volume according to the classical optimal jamming theory [2]. Because

the influence of a particular jamming mode on communication is not unique, it cannot meet the uniqueness requirement.

According to the conventional optimal communication jamming theory, when the volume of the communication signal is larger than the volume of the jamming signal, anti-jamming can be realized. From this perspective, we can try to classify anti-jamming strategies. Different from the perspective of jamming pattern, the anti-jamming strategy usually only deals with one domain of the signal, so it can meet the unique requirement when it is classified by domain. Meanwhile, according to the optimal jamming theory, the anti-jamming decision is a reverse operation to realize the optimal jamming condition, and its action space is all contained in the action space of changing the volume element of communication signal, so the domain division also meets the requirement of completeness. Therefore, this paper will divide anti-jamming strategies into frequency domain, power domain, time domain and so on according to anti-jamming elements.

Construction Results. Adaptive frequency changing, adaptive frequency hopping and accelerating frequency hopping are all anti-jamming strategies in frequency domain. It is obvious that the adaptive frequency modification only changes the working frequency band of communication from one frequency to another, and the bandwidth does not change. Adaptive frequency hopping and accelerating frequency hopping are the anti-jamming methods of frequency hopping, and frequency hopping itself belongs to the anti-jamming method of spread spectrum communication. Therefore, these anti-jamming methods in the frequency domain can be further classified into 'non-spread spectrum mode' and 'spread spectrum mode'.

Power adaptation is a power domain anti-jamming strategy. The basic principle is to adjust the power of communication signal to meet the requirement of bit error rate or transmission rate according to the change of interference power. Therefore, power adaptation can be classified as 'adjusting the power of communication signal'.

Adaptive time hopping is an anti-jamming strategy in time domain. Time division multiplexing technology is to divide the time of transmission information of the whole channel into several time slices (time slots for short), and allocate these time slots to each information source for use. Analogous to the concept of time division multiplexing, adaptive time hopping can also be regarded as dividing the whole communication time period into segments. Communication signals and jamming signals are regarded as two information sources or users, and all time slots are allocated to these two users. When there is jamming in the time slot, it is equivalent to allocating these time slots to users of the jamming source. When there is no jamming in the time slot, it is regarded as assigned to the communication user. Therefore, this anti-jamming mode similar to time division multiplexing can be summed up as 'time division multiplexing like mode'.

In the practical application, the commonly used anti-jamming strategies also include modulation coding. Different from the above three anti-jamming strategies, modulation coding belongs to the anti-jamming strategy in the modulation coding domain, so modulation coding mode should be added to the classification of anti-jamming strategies, which indicates that the ontology scale will be expanded according to the actual application in the process of ontology construction.

4 Results and Application

4.1 Overview of Anti-jamming Knowledge Graph

This paper uses the graph database Neo4j to store and construct the anti-jamming knowledge graph. Neo4j is a graph database based on the attribute graph model. Its storage management designs special storage schemes for nodes, node attributes, edges, and side attributes in the attribute graph structure, which can access graph data more efficiently than relational databases in the storage layer.

According to the construction method in Sect. 3, the processed RDF data were input into Neo4j software through the Java program written to form the anti-jamming knowledge graph of conventional interference style as shown in Fig. 2.

Fig. 2. Anti-jamming knowledge graph of conventional jamming patterns

4.2 Relationship Expansion of Anti-jamming Knowledge Graph

Jamming Patterns. As shown in Fig. 3, the anti-jamming knowledge graph is expanded from the perspective of jamming pattern, so that the relationship directly linked to different jamming pattern can be searched. For example, selecting wide-band blocking jamming is from eight kinds of conventional jamming in the anti-jamming graph, its triplet relationship can be searched to obtain the style characteristics, jamming attributes and anti-jamming methods. These relations are also related to some other jamming styles, indicating that there is a certain relationship between several jamming styles.

Fig. 3. Relationship expansion from perspective of jamming patterns

Pattern Features. From the perspective of pattern features, the anti-jamming knowledge graph can search for specific patterns and anti-jamming methods pointed by pattern features. In practical application, the steps of perceiving specific pattern can be eliminated, and the corresponding processing methods can be found directly through the search of pattern features. For example, by searching the feature "full time frequency gap exists" among several pattern features, the jamming pattern, processing mode and important parameters of this feature can be searched, and the corresponding processing means of different features can be quickly found (Fig. 4).

Fig. 4. Relationship expansion from perspective of pattern features

5 Conclusion

In this paper, an anti-jamming knowledge graph construction process based on conventional jamming patterns is proposed. Using this process, the conventional jamming pattern information is extracted and processed to form the data layer entity of anti-jamming knowledge graph. The pattern layer ontology of anti-jamming knowledge graph is constructed by sorting the data layer upward and classifying it. Based on the graph database software, the anti-jamming knowledge graph relationship was expanded from different perspectives. Next step, to deal with the different jamming pattern information input of sensing modules, propose an efficient knowledge graph searching and decision-making method, and form an effective decision-making system based on anti-jamming knowledge graph.

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