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RESEARCH RESULTS
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RAIL-CR: RAILROAD COGNITIVE RADIO

SUMMARY

Robust, reliable, and interoperable wireless communication devices or technologies are vital to the success of positive train control (PTC) systems. Accordingly, the railway industry has started adopting software-defined radios (SDRs) for packet-data transmission. SDR systems realize previously fixed components as reconfigurable software. Recognizing the potential uses of SDRs for PTC systems, this project developed a railway cognitive radio (Rail-CR) that implements artificial intelligence decisionmaking capability in concert with an SDR to adapt to changing wireless conditions and learn from past experience. Objectives of the project included: developing a concept of operations for wireless data communication link adaptation based on use-case scenarios for packet radio systems; designing and implementing decisionmaking architecture on an SDR; designing strategies for radio environment observations; defining operational objectives and performance metrics; and designing and exercising a test plan to demonstrate performance under varying conditions.

The decisionmaking architecture of the Rail-CR, as shown in Figure 1, begins with observations of the wireless operating environment and performance metrics. An event, such as an increase in ambient noise or a jamming signal that degrades performance, defines when the cognitive engines (CEs) engage. The architecture enables adaptation to new situations and the capability to learn from past decisions. The Rail-CR was tested under a variety of interference conditions designed to simulate real-world experiences.

Each test case compared the SDR with no cognition to cognitive operations. Results show that a radio operating with no cognition was unable to mitigate interference conditions causing either significantly high errors or a loss of connectivity. By changing SDR parameters, the CE was able to successfully address these issues.

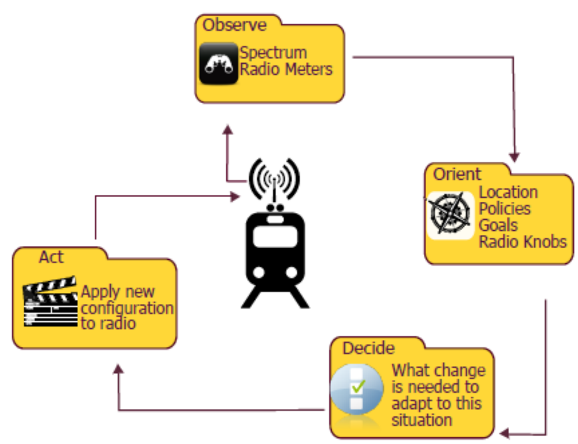

Figure 1. Decisionmaking Cycle

BACKGROUND

By using communication, computing, and related technologies, PTC systems aim to improve system safety and efficiency, and help safeguard against human-operator error. Wireless communication is an integral part of PTC, and its performance directly impacts the operation and effectiveness of PTC systems.

Traditionally, the radios used for voice and data communications have been fixed-functionality radios. Today, more industries have adopted SDRs because the functionality and operating parameters can be controlled by software and reconfigured in the field. SDRs allow for real-time control of radio operating parameters and provide access to certain observable parameters and measurements that may help determine state information and communication link performance.

OBJECTIVES

The objective of this project is to develop a Rail-CR for link adaptation based on packet radio operations among locomotives, base stations, and wayside signal switches.

The development of the Rail-CR has four key aspects: defining the railroad-specific scenarios and test cases; developing the Rail-CR architecture and associated learning and decisionmaking algorithms; integrating the Rail-CR with an SDR; and implementing the test cases and performance evaluation.

The Rail-CR decisionmaking cycle was inspired by human processes. The engine first detects spectrum conditions and performance metrics to determine whether operations are within predefined specifications. User-defined thresholds, such as maximum allowable packet error rate (PER) or required throughput, provide guidelines for whether CE engagement is required.

A railway concept of operations for a Rail-CR provides the guidelines for defining performance thresholds. Typical requirements might include the ability to function in a noisy environment or in the presence of a jamming signal, as well as the ability to improve link performance and operate in line with defined Federal Communications Commission, local, and international spectrum policies.

METHODS

A goal for the Rail-CR was to make the architecture modular and adaptable to different hardware and application platforms. Rather than tie it to one specific radio, the CE was designed with a 'middleware' interface that is customizable for specific hardware platforms. Figure 2 illustrates the architecture of a universal serial radio peripheral and its associated digital signal processing packages. The middleware module contains the link between control commands and parameter operations, including performance metric collection and transmission parameter changes made by the CE and passed into the software that controls the SDR.

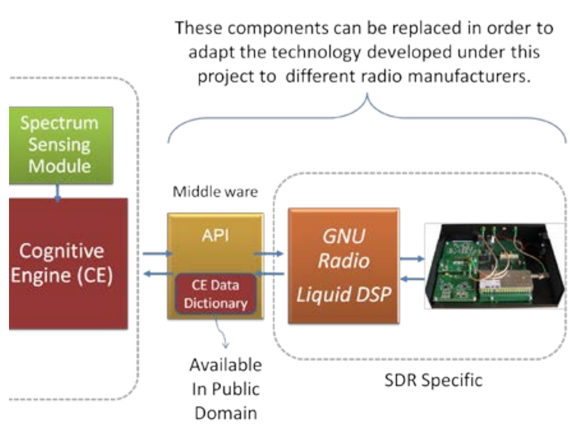

Figure 2. Modular Architecture

The test plan consisted of sending a data file across a wireless link in the presence of varied sources of interference. Performance was compared with and without the CE activated. The tests were performed in an outdoor railway environment under static conditions.

FINDINGS

The cognitive engine architecture developed is shown in Figure 3. The architecture first searches past decisions to determine whether previous experience can meet the current need. If no past scenarios match the current situation, then an optimization routine identifies a solution. The engine implements the decision and verifies if it led to performance improvement. In this way, the engine equipped with Rail-CR can learn from every new successful decision so that the next time it experiences a similar event it can retrieve previous data.

Table 1 lists the test results comparing no-cognition to cognitive operations.

Table 1. Performance Comparison between Cognitive and Noncognitive Operations in the Rail Yard

Env.		PER	Throughput (bps)	Spectral Efficiency (b/s/Hz)	Fitness
Amb.	No-CE	0.035	3.74E+05	1.8708	0.5968
	CE	0.031	4.54E+05	2.2717	0.5548
Wide	No-CE	1	0	0	0
	CE	0.036	1.60E+05	0.7987	0.4866
Jam	No-CE	1	0	0	0
	CE	0.089	1.57E+05	0.7843	0.4476
Hop	No-CE	1	0	0	0
	CE	0.137	1.25E+05	0.6261	0.3052
Fade	No-CE	1	0	0	0
	CE	0.151	83060	0.4153	0.24

Figure 4 compares performance between noncognitive and cognitive operations in the rail yard testing scenario in terms of overall fitness performance. Fitness is an aggregate combination of all of the performance metrics where 1 is the highest possible and 0 is a disconnect.

The noncognitive tests were unable to maintain connectivity, whereas the cognitive engine was able to adapt to changing conditions.

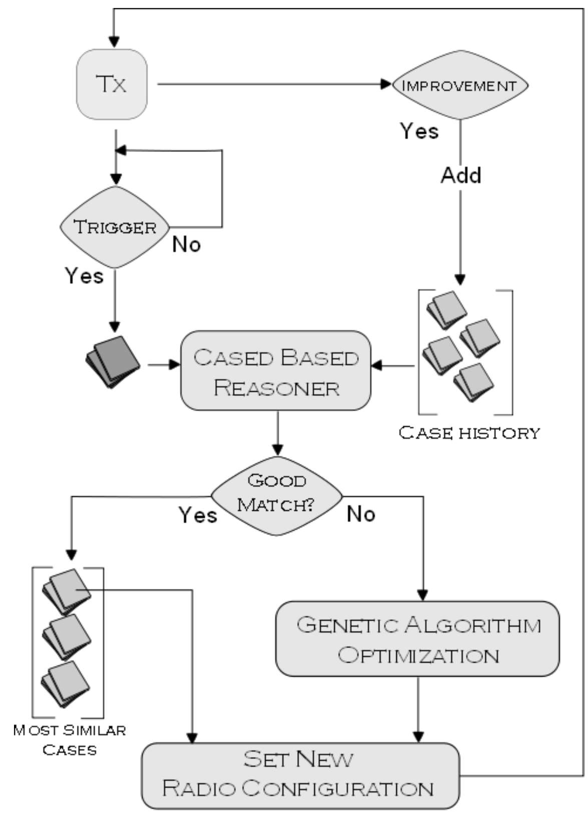

Figure 3. Cognitive Engine Architecture

CONCLUSIONS

The noncognitive operations' loss of wireless connectivity has implications for operational efficiency and safety. Slowing down upon approaching a signal to regain connectivity incurs delays which impact revenue and may potentially affect safety. Cognitive operations, on the other hand, can reduce the need for additional repeaters and associated infrastructure/maintenance costs. These findings point to the prospect of improved spectrum efficiency and interoperability between carriers, which will take on greater importance as PTC system requirements and usage grow.

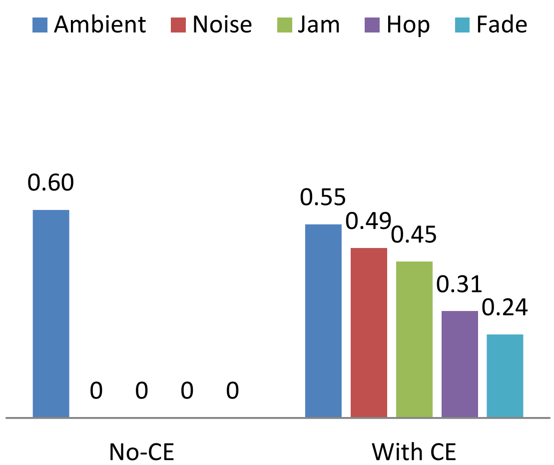

Figure 4. Fitness Comparison

FUTURE ACTION

The next steps for this research involve increasing the number of cognitive links operating at the same time. This scalability will address synchronization issues caused by multiple locomotives communicating simultaneously with the same signal. Improving time-to-decision and transitioning the architecture to hardware-only platforms present additional challenges.

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KEYWORDS

Cognitive radio, decisionmaking, software defined radio (SDR), positive train control (PTC), wireless