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WIRELESS COEXISTENCE: CONCEPTS AND IMPLICATIONS IN THE MINING INDUSTRY

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ABSTRACT

The ability of wireless systems—e.g., voice communication, proximity detection, tele-remote operation, telemetry, etc.—to function satisfactorily (coexist) in the presence of other wireless systems is critical to the safety and health of mine workers. The failure of wireless systems to coexist could result in the delay, corruption, or outright loss, of critical data, voice, or video information. However, no mining-sector-specific regulations, standards, or guidelines exist to ensure the safe coexistence of wireless systems. This paper introduces the concept of wireless coexistence, implications in the mining industry, and the National Institute for Occupational Safety and Health's (NIOSH's) research approach to develop guidelines and recommendations to ensure safe wireless coexistence.

INTRODUCTION

Complex electronic systems are becoming commonplace in the mining industry. The need for these systems to function properly is often critical to miner safety and health. The ability of electronic systems to function properly in the electromagnetic environment in which they operate is known as electromagnetic compatibility (EMC) [1-3]. However, all electrical and electronic systems, whether intentionally or unintentionally, transmit and may receive electromagnetic energy. The intentional or unintentional transmission or unintentional reception of electromagnetic energy that adversely affects the ability of systems to function acceptably is a phenomenon known as electromagnetic interference (EMI) [1-3].

As a result of the evolving complexities and applications of systems using wireless technologies, the ongoing reallocation of radio frequency (RF) spectrum, and the increased use of unlicensed and shared spectrum, the ability of wireless systems to coexist has been identified as a requirement to ensure overall EMC [4]. Focusing specifically on RF transceiver systems, wireless coexistence differs from EMI in that, as the National Institute of Standards and Technology (NIST) states, *"Coexistence implies measuring the mutual interaction between multiple communications systems simultaneously. Interference is focused on only the impacted system and may cause both communication and basic operation disruptions."* [4]**.**

At the simplest level, wireless coexistence can be defined as the ability of wireless systems to function satisfactorily in the presence of other wireless systems. The Institute of Electrical and Electronics Engineers (IEEE) more specifically defines wireless coexistence as the ability of one wireless system to perform a task in a given shared environment where other systems have an ability to perform their tasks and might or might not be using the same set of rules [5].

However, ensuring wireless system coexistence is challenging and implies *"…allowing and measuring the mutual interaction between multiple communications systems"* [4, 6]. As such, defining a failure of wireless systems to coexist is complex, and the application of wireless systems must be carefully considered when defining failure metrics [4]. The allowable amount of performance degradation due to a mutual interaction of wireless systems could vary dependent upon the application. Furthermore, coexistence testing is not simply about the unit-under-test or system-under-test but *"…how much impact the unit-under-test (UUT) or system-under- test (SUT) causes to other users of the spectrum"* [6]. In essence, a wireless system cannot be tested for coexistence on its own because the mutual interaction with other wireless systems in its intended operational environment must be tested [4].

WIRELESS COEXISTENCE IN INDUSTRIAL AND MEDICAL SECTORS

The industrial and medical sectors have recognized the need for wireless coexistence with U.S. Federal agencies taking a proactive approach to the problem in the medical sector.

The International Society for Automation (ISA), NIST, SINTEF, and VDI/VDE-2185 all discuss the importance of wireless system coexistence [7-10]. Numerous standards involving wireless system coexistence have been developed and continue to evolve [11-15]. However, whitepapers, conference proceedings, and peer-reviewed publications continue to present concerns regarding the ability of wireless systems operating in unlicensed or shared spectrum to coexist [16-22].

Three federal agencies, the National Institute for Standards and Technology (NIST), the Food and Drug Administration (FDA), and the Federal Communications Commission (FCC), have taken proactive approaches in recognizing the risks and acknowledging concerns regarding wireless coexistence. NIST states, *"Coexistence concerns are driven by the increase in the use of wireless technology to connect critical equipment, the higher density of sensitive equipment (e.g., health care facilities) and the intensive use of unlicensed or shared spectrum."* [4]. In a joint statement, the FDA and FCC assert in part, *"Developing and integrating wireless and broadband communications technology with medical devices and applications requires agencies to assure that such devices operate in a safe, reliable and secure manner."* [23]. In 2013, the FDA assumed a leadership role by recommending *"…addressing such risks through testing for coexistence of the device wireless system in the presence of the number and type of in-band sources expected to be in proximity to the device"* as part of a wireless technology guidance document for industry and Food and Drug Administration staff [24].

IMPLICATIONS IN MINING

The need for wireless system coexistence in the mining sector has already become apparent. For example, a global computer network equipment provider states as part of its guidance on wireless network requirements for an autonomous vehicle underground mining system that no other systems should be using the 2.4 GHz industrial, scientific, and medical (ISM) spectrum in the area where their system is to be deployed [25]. In addition, mines employing Wi-Fi based solutions often prohibit the use of specific channels (blacklisting) by other wireless systems to prevent potential life-threatening malfunctions of safety- critical systems [26].

Coexistence issues on mine sites may be created by unexpected or unknown wireless sources. As has been shown in demonstrations of self-driving vehicles, the presence of unexpected wireless signals can cause critical systems to malfunction [27]. The addition of wireless signals, such as 4G or 5G cellular systems, in an area neighboring a mine site could potentially cause intermittent and difficult-to-troubleshoot coexistence issues. A similar situation recently occurred in the aviation industry with the introduction of 5G cellular systems near airports which negatively impact RADAR altimeters of airliners upon landing approach [28, 29].

The automotive industry has raised coexistence concerns regarding cross-technology interference with in- or on-vehicle wireless systems [30, 31]. Cross-technology interference is a term used to describe the inability of low-power systems operating in ISM frequency bands to coexist [16]. Cross-technology interference is extremely relevant to the mining industry when retrofitting older equipment with wireless systems used for proximity sensing, vehicle telemetry monitoring, tele-remote operation, etc. Wireless systems from varying vendors operating in close proximity on mining equipment have a much higher probability of causing a malfunction in unrelated wireless systems that could result in death or injury.

In addition to the potential for injuries or fatalities, the inability of wireless systems to coexist can result in unreliable operation of systems that are very complex in nature, time consuming to troubleshoot, and most often require highly specialized skillsets to determine appropriate resolutions [32]. For these reasons, ensuring wireless system coexistence is best approached proactively rather than reactively.

In the U.S. mining industry, the concern regarding the ability of wireless systems to coexist is compounded by at least two factors. First, mine operators and smaller wireless system mining technology and equipment manufacturers may not be fully aware of the crucial need for the coexistence of wireless systems. Second, the FCC does not regulate frequency (spectrum) allocation or usage for tunnel (underground) radio systems, thus significantly increasing the risk for wireless system coexistence issues [33].

Similar to the industrial and medical sectors, the ongoing adoption of wireless technology—particularly for automated and autonomous systems—in the mining industry will likely lead to systems with an inability to coexist, possibly posing unnecessary risks to miner safety, if corrective measures are not taken. In addition, as coexistence issues become apparent in the mining industry, mines may be hesitant to adopt wireless technologies, including those systems designed to improve miner safety and health.

NIOSH RESEARCH

Recognizing that coexistence is critical to the safe application of wireless systems in the mining industry, NIOSH has started a research project titled "Coexistence and Safety of Wireless Systems in Mining." The project will take a diverse research approach with the goal to provide the mining industry with specific guidelines, recommendations, and test methodologies to ensure safe coexistence of wireless systems.

First, NIOSH researchers will become actively involved in guidelines- and standards-settings working groups to stay abreast of emerging wireless technology and coexistence trends in nonmining industrial sectors and provide input on mining-related concerns.

Second, focusing on the industrial automation, oil and gas, and medical sectors, NIOSH researchers will perform an extensive literature review of existing and proposed standards, guidelines, and recommendations to better understand best practices adopted in other industrial sectors to ensure wireless system coexistence. NIOSH researchers will also attend relevant wireless and mining conferences to obtain information on emerging wireless technologies and to better understand the types of wireless systems and technologies that are being introduced to, and adopted by, the mining industry.

And third, in partnership with NIST, NIOSH researchers will use the information gathered through the participation in standards-settings groups, literature reviews, and conference attendance to identify wireless systems with potential inabilities to coexist that have been or could be adopted by the mining industry. Experiments will then be performed on the identified wireless systems to demonstrate how unsatisfactory wireless system performance would pose safety hazards to miners. In addition, researchers will use the information to identify key performance metrics necessary to define satisfactory wireless system performance and develop mining-sector- specific methodologies to test for wireless systems coexistence.

RESEARCH OUTCOMES

Researchers will develop mining-sector-specific guidelines and recommendations on identifying key wireless system performance metrics needed to test for coexistence. Researchers will also develop methodologies to test for wireless system coexistence based on the identified key performance metrics. These guidelines, recommendations, and test methodologies will allow mine owner/operators and wireless technology innovators to proactively test wireless systems' abilities to safely coexist before life-threatening problems arise. In addition, to ensure overall wireless system reliability, researchers will develop and disseminate guidelines and recommendations for mine owner/operators to develop and implement wireless plans for mine sites.

SUMMARY

The ability to coexist is and will become increasingly critical to the safe application of wireless systems in the mining industry. However, no mining-sector-specific regulations, standards, or guidelines exist to ensure safe coexistence. NIOSH's Coexistence and Safety of Wireless Systems in Mining project will help overcome this problem by providing the mining industry with guidelines, recommendations, and test methodologies needed to test wireless systems for safe coexistence.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company name or product does not constitute endorsement by NIOSH.

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