LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-CONF-231891

Remote Monitoring and Tracking of UF6 Cylinders Using Long-Range Passive Ultra-wideband (UWB) RFID Tags

Faranak Nekoogar, Farid Dowla

June 18, 2007

Remote Monitoring and Tracking of UF6 Cylinders Using Long-Range Passive Ultra-wideband (UWB) RFID Tags
Tucson, AZ, United States
July 8, 2007 through July 12, 2007

Remote Monitoring and Tracking of UF6 Cylinders Using Long-Range Passive Ultra-wideband (UWB) RFID Tags

Faranak Nekoogar, Farid Dowla
Lawrence Livermore National Laboratory
Livermore, CA, USA

ABSTRACT[1]

An IAEA Technical Meeting on Techniques for IAEA Verification of Enrichment Activities identified "smart tags" as a technology that should be assessed for tracking and locating UF6 cylinders. Although there is vast commercial industry working on RFID systems, the vulnerabilities of commercial products are only beginning to emerge. Most of the commercially off-the-shelf (COTS) RFID systems operate in very narrow frequency bands, making them vulnerable to detection, jamming and tampering and also presenting difficulties when used around metals (i.e. UF6 cylinders). Commercial passive RFID tags have short range, while active RFID tags that provide long ranges have limited lifetimes. There are also some concerns with the introduction of strong (narrowband) radio frequency signals around radioactive and nuclear materials. Considering the shortcomings of commercial RFID systems, in their current form, they do not offer a promising solution for continuous monitoring and tracking of UF6 cylinders.

In this paper, we identify the key challenges faced by commercial RFID systems for monitoring UF6 cylinders, and introduce an ultra-wideband approach for tag/reader communications that addresses most of the identified challenges for IAEA safeguards applications.

1

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.UCRL-ABS-228546

I. INTRODUCTION

On-demand real-time identification and tracking of UF6 cylinders using radio-frequency identification (RFID) tags is a powerful technology for improving enrichment safeguards to prevent proliferant states from having unfettered and clandestine access to sensitive nuclear conversion and enrichment technology. RFID tags offer timely detection, remote monitoring, and tracking of UF6 cylinders to provide a substantial improvement in the continuity of knowledge at various stages of enrichment process, ensuring appropriate response for any potential diversion event, while reducing maintenance requirements and human factor related errors.

Although the concept of using RFIDs for tracking UF6 cylinders poses an attractive solution to safeguards security, there are major obstacles on the way of achieving this goal. To date, most of the commercially available RFID systems use narrowband technology for their tag-reader communications. Therefore, continuous waveforms (CW) are used to transfer information between tags and readers, which can potentially create the following limitations and challenges in their performance:

- ***Signal jamming:*** The narrowband signals used in RFID systems have well defined RF energy in narrow frequency bands that makes them very vulnerable to intercept and detection. Therefore such signals can be easily jammed to allow tampering with security and monitoring systems.

- ***Signal blockage:*** High frequency RF signals are highly attenuated by walls and equipment. This can lead to system reliability issues when monitoring moving objects indoors if site specific geometry is not adequately addressed during system design and installation.

- ***Orientation dependence:*** Most of the current commercial RFID transponders and readers exhibit some orientation dependence. Therefore, tags and readers must be positioned in a preferred direction for optimum transfer of information. This dependency limits the maximum reliable range of most RFID systems.

- ***High power used by active tags:*** In order to provide the long range, active tags consume a relatively large amount of transmitting power, which limits their lifetime and causes them to be larger in size and more expensive than passive tags.
- ***Limited range for passive tags:*** The short range introduced by magnetic based solutions prevents passive tags to be used in many applications that require longer range.
- ***Poor performance around metallic surfaces:*** One of the major challenges of the current RFID systems based on narrowband technology is their poor performance around metallic surfaces such as UF6 cylinders. This is due to multipath phenomenon caused by reflection of continuous RF waveforms from metallic surfaces that can destructively add and degrade the transmitted signal.
- ***Limitations to worldwide operation:*** Operation of the currently available RFID systems is limited to the specific narrowband frequencies used by the readers and transponders. By regulations, some frequencies are not available in different parts of the world, which limits the worldwide operation of RFID systems based on specific frequencies.

Much of these problems can be addressed through the use of ultra-wide band (UWB) technology for tag-reader communications is RFID systems.

II. UWB TECHNOLOGY & RFID

Ultra-wideband communication systems employ very narrow (pico-second to nano-second) radio frequency (RF) pulses to transmit and receive information. Using narrow pulses as the building block for communications offers several advantages in wireless communications that can be very beneficial to RFID tags. The short duration of ultra-wideband pulses provides very wide bandwidth (in the range of GHz) with low power spectral density (PSD). The low PSD enables UWB signals to share the RF spectrum with currently available radio services with minimal or no interference problems. Therefore, no expensive licensing of the spectrum is required for UWB systems. Fig. 1

compares UWB power spectral density with the co-existing narrowband and wideband technologies.

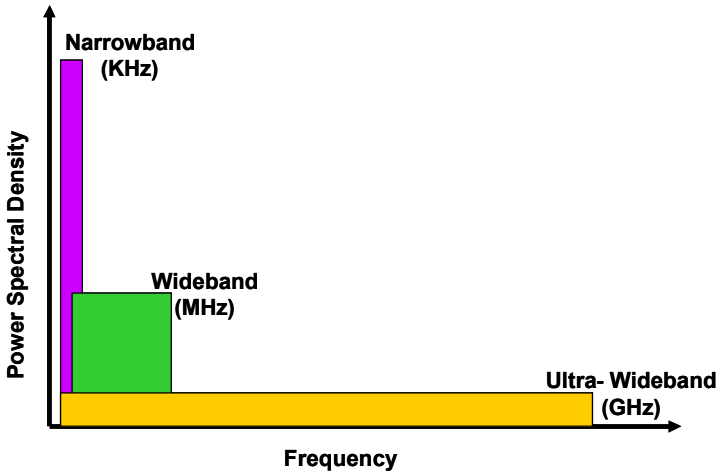

Figure 1: Co-existence of UWB signals with narrowband and wideband signals in RF spectrum

UWB pulses reside below the noise floor of a typical narrowband receiver; therefore, they become undetectable from background noise and in most cases only the intended receiver is able to detect them. Hence UWB tags are not as vulnerable to detection, intercept, and jamming as narrowband tags are. Furthermore, due to their large bandwidth and frequency diversity, UWB pulses are less sensitive to multipath effects than CW signals and can provide excellent spatial resolutions (cm accuracy). The fine spatial resolution makes UWB systems useful for RFID applications in heavy metallic channels such as metallic surfaces of UF6 cylinders. In addition, the lower frequencies covered by large UWB bandwidth offers good penetration properties, which provides through the wall communications and overcomes the signal blockage problem that is currently a weakness in narrowband UHF RFID tags. Moreover, UWB systems have fewer components and can be manufactured in smaller form factor compared to typical narrowband communication systems, which makes them viable candidates for RFID tags.

III. LLNL's UWB RFID TAG

In this section we introduce a novel passive, long range RFID tag (developed at Lawrence Livermore National Laboratory) that can perform well around metals and provides geo-location capability for real time tracking of UF6 cylinders.

Unlike conventional, battery-operated (active) RFID tags, LLNL's small UWB tags, called "UTag", operate at relatively long ranges (up to 20 meters) in harsh propagation channels such as heavy metallic environment caused by UF6 cylinders in a cylinder storage yard.

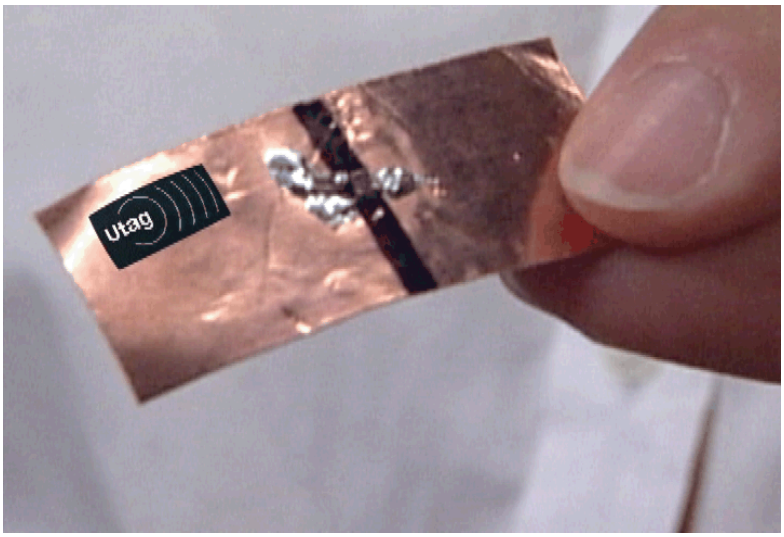

Figure 2: LLNL's UTag lab prototype.

Since "UTag" is battery-less (that is, passive), they have practically unlimited or unrestricted lifetimes without human intervention, and they are lower in cost to manufacture and maintain than active RFID tags. These robust, energy-efficient passive tags are remotely powered by UWB radio signals, which are much more difficult to detect, intercept, and jam than conventional narrowband frequencies. The features of long-range, battery-less, energy-scavenging capability, and low-cost give UTag significant advantage over other existing RFID tags.

IV. UNIQUE CHARACTERISTICS OF "UTags"

UTags have the following innovative characteristics that take advantage of UWB technology:

Immune to Signal Blockage

UTags perform in harsh, cluttered environments. Our UWB tags activate and transmit in environments where a GPS system might fail. UWB frequencies penetrate most low-conductivity materials; thus, UWB tags perform through walls; glass; buried in dirt; inside concrete buildings and in warehouses vaults, airplanes, ships; and outside in landscapes full of rocks, trees, people, and buildings. Therefore, Line-Of-Sight (LOS) is not needed for UTags operation.

Low Complexity, Low Cost

UTags have few components, making them easy and inexpensive (less than $1) to manufacture by conventional electronic manufacturing methods. UWB frequencies are available worldwide, making them ideal for global applications. Their lower cost and small size (about that of a quarter) make their use with lower value items or small pieces of equipment feasible.

Undetectable

UWB pulses reside below the noise floor of a typical narrowband receiver, becoming undetectable from background noise. Only the intended receiver is able to detect the UWB pulses.

Multi-tag Interrogation

In inventory and tracking systems involving multiple UTags—such as tags attached to UF6 cylinders, low frequency UWB signals from a transmitter, power all UTags simultaneously. Once the UTags are all awake, the UWB interrogator sends specific "interrogating codes" to the tags. The unique interrogating code triggers the appropriate UTag to respond with its unique "response code," using the backscattering techniques.

Using this method, multiple UTags can be read without any interference from other UTags communicating with the reader. In addition, no high power synchronization technique is required to separate each UTag's information from another's.

Geolocation of UTags

The ability to geo-locate (not just detect) a tag in 3-D (x-, y- and z) is very important in UF6 cylinder monitoring. The UTag has good geolocation capabilities. Range measurements are often the initial step in many geolocation problems. Based on statistical signal processing of wide band RF waveforms, we additionally have incorporated into our design a high-accuracy indoor ranging device with the UWB RF pulsing using low-power and low-cost electronics. We have shown that wideband UTag signals are particularly suited to ranging in harsh RF environments because they allow signal reconstruction in spite of multipath propagation distortion caused by metallic surfaces and cluttered environments.

V. CONCLUSIONS

In this paper we presented the limitations of the commercially available RFID systems for remote monitoring and tracking of UF6 cylinders and discussed the advantage of using ultra-wideband technology in such systems. Furthermore, we introduced LLNL's novel passive and long range tag with geo-location capability for use in UF6 cylinder tracking systems.