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Authenticated Tracking and Monitoring System (ATMS) Tracking Shipments from an Australian Uranium Mine

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Abstract—The Authenticated Tracking and Monitoring System (ATMS) answers the need for global monitoring of the status and location of sensitive items on a worldwide basis, 24 hours a day. The ATMS concept uses wireless sensor packs to monitor the status of the items and environmental conditions, to collect a variety of sensor event data, and to transmit the data through the INMARSAT satellite communication system, which then sends the data to appropriate ground stations for tracking and monitoring. Authentication and encryption algorithms are used throughout the system to secure the data during communication activities. A typical ATMS application would be to track and monitor the safety and security of a number of items in transit along a scheduled shipping route. The resulting tracking, timing, and status information could then be processed to ensure compliance with various agreements.

Following discussions between the Australian Safeguards Office (ASO), the U.S. Department of Energy (DOE), and Sandia National Laboratories (SNL) in early 1995, the parties mutually decided to conduct and evaluate a field trial prototype ATMS to track and monitor shipments of uranium ore concentrate (UOC) from a currently operating uranium mine in Australia to a final destination in Europe. This trial is in the process of being conducted on a worldwide basis with tracking and monitoring stations located at sites in both Australia and the U.S. This paper describes the trial.

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1. INTRODUCTION

The Authenticated Tracking and Monitoring System (ATMS) addresses the status and location of proliferation-sensitive items during shipment. The ATMS tracks and monitors items in transit (or stationary) from a mobile or fixed ground monitoring station (see Figure 1). Wireless sensor packs provide near-real-time event and state-of-health (SOH) data, which are collected by a processing unit and transmitted to ground stations through a satellite communications link (the International Maritime Satellite, INMARSAT). Position information is provided by Global Positioning System (GPS) satellites. The major benefit of the ATMS is its ability to monitor virtually any shipment regardless of the transportation mode (rail, truck, or ship) anywhere in the world.

Applications for the ATMS include arms control, verification of nonproliferation treaties, military asset control (location and status), or any type of bilateral or multinational nuclear-weapons dismantlement agreement. The Department of Energy (DOE) and the Defense Special Weapons Agency (DSWA) jointly sponsored the development of ATMS at Sandia National Laboratories (SNL). Commercial applications for ATMS include inventory control and tracking of any high-value items.

Discussions were held between the Australian Safeguards Office (ASO), DOE, and SNL in early 1995 regarding the practical application of the ATMS. It was proposed and accepted that a field trial, evaluation, and demonstration of the proof-of-concept of ATMS be conducted on shipments of uranium ore concentrate (UOC) from one of the two

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Figure 1. ATMS Operational Concept

currently operating uranium mines in Australia to a destination in Europe. This trial will be conducted on a worldwide basis with monitoring stations located in both Australia and the U.S. Evaluation and feedback information obtained from this first-time worldwide trial will be extremely useful in the future and final development of ATMS.

2. ATMS CONCEPT OVERVIEW

The ATMS concept uses an authenticated wireless radio frequency (RF) sensor subsystem, modeled after the Authenticated Item Monitoring System (AIMS), to monitor shipment status. The AIMS sensor suite can detect item motion/movement, intrusion, safety concerns, environmental conditions, and containment. An authentication/encryption algorithm provides a high degree of system data security.

Dynamic shipment location and tracking information is obtained through on-board GPS receivers. The resulting sensor data and dynamic location

information are then combined and transmitted using both encryption and authentication via the worldwide INMARSAT satellite system. These data are then relayed to monitoring and tracking ground stations in near-real-time (e.g., 5 minutes). These ground stations display shipment location/tracking and sensor status using Microsoft® Windows™-based software and information management utilities. As an overview, the block diagram of the current proof-of-concept ATMS is shown in Figure 2.

The left side of the diagram depicts the wireless AIMS sensor subsystem (contained within the dotted line). The AIMS sensor information, obtained from the Receiver Processing Unit (RPU), is periodically combined (e.g., every 5 minutes) with the current GPS position data by the Communications Control Unit (CCU). Once the sensor and position information are combined, this information is queued for transmission. Once the proper transmission time interval has expired, the combined data are then encrypted and authenticated by the CCU and transferred to the outbound

INMARSAT transceiver for satellite transmission over the INMARSAT worldwide network. This information is then received by one of many INMARSAT Land Earth Stations (LESs), where it is then re-transmitted back to the satellite network for subsequent reception by the appropriate mobile monitoring ground stations.

Once the ground station receives this encrypted and authenticated information from the incoming INMARSAT transceiver, it is sent to the Ground Station Processing Unit (GPU), where the location and sensor information is decrypted and/or authenticated and put into a "clear" form. This clear or "plain text" information is then sent to a standard PC-based Tracking and Sensor Display Unit (TDU). (Either a PC workstation or a laptop PC is used for the TDU.) The TDU, loaded with the appropriate

maps and tracking software, displays in a tracing manner where the shipment has previously been and currently is, along with current and past AIMS sensor information. This tracking and sensor status information is displayed in a very user-friendly manner using a Windows™-based environment. It should be noted that not only is the shipment platform completely mobile on a worldwide basis, so too is the ground station. There are no ground station requirements for even a telephone link; all that is required is power, and even that can be supplied by batteries for very remote monitoring applications.

To show how the status of typical shipments can be monitored, Figure 3 and Figure 4 show two examples of typical shipping scenarios and their shipment platforms. Figure 3 depicts a shipment by

Figure 2. ATMS Block Diagram

Vehicle Shipment Tracking and Monitoring Application

Figure 3. ATMS Shipment by Truck

Figure 4. ATMS Shipment by Sea Vessel

truck while Figure 4 depicts a shipment by sea. Many other shipment scenarios are possible, including railcar.

3. ATMS SENSOR SYSTEM

The battery-powered AIMS secure sensor transmitter (SSTX) packs report authenticated significant sensor activations, known as "events," to the nearby RPU. In addition to event reporting, each sensor sends periodic authenticated messages that indicate the SOH of each sensor, and thus assures that all sensors are on-line and have not been tampered with. The RPU processes and packetizes all incoming sensor pack messages and then sends this information to the CCU for subsequent satellite transmission via the INMARSAT transceiver.

Environmental and safety sensors detect and report conditions surrounding the selected items that exceed acceptable limits (e.g., temperature trip points). Environmental sensors include smoke detectors, temperature detectors, humidity detectors, flame detectors, radiation detectors, and chemical detectors. Containment sensors monitor the physical emplacement of selected items and thereby verify that they have not been moved or tampered with. As an example, active fiber-optic seals are

routed through container turnbuckle tie-downs so that it is extremely difficult to move or remove the selected item without breaching the fiber-optic loop, thereby causing an event. Containment sensors include motion sensors, active fiber-optic seals, and load cells/links. Intrusion detection sensors can monitor the physical presence and movement of an individual in the area of the selected item or an attempt to enter the area containing the item. Intrusion detection sensors include microwave detectors, infrared detectors, balanced magnetic switches, and wire grid detectors.

Figure 5 shows a variety of AIMS/ATMS sensor packs, both analog and bi-level, in various packaging arrangements for different applications.

In summary, the activation of sensor inputs, sensor pack tampering, missing SOH messages, or messages that are not properly authenticated comprise events that are time-tagged by the RPU and immediately transferred via the CCU to the transceiver of satellite transmission and subsequent ground station reception and display.

4. ATMS CURRENT STATUS

ATMS was born with a proof-of-concept demonstration in August 1993. Using equipment borrowed from other projects, a road shipment of mock weapon containers was successfully tracked and monitored for three days as it traversed five

Figure 5. AIMS/ATMS Secure Sensor Transmitter (SSTX) Packs

western states in the U.S. Sufficient interest was generated to fund, beginning in mid-FY94, the development of a field prototype. Initial tasks included developing system requirements, obtaining INMARSAT licensing, designing the communications control and ground station processing units, procuring prototype hardware, and rudimentary encoding software.

The first field prototype, completed in FY96, included two-way radio communication between the monitoring station (either fixed or mobile) and the cargo vehicle, authentication and encryption of the INMARSAT data channel, and a user-controlled software interface that provided tracking and cargo monitoring information displays on an interactive control screen.

During the latter part of FY96 and early FY97, the ATMS field prototype was successfully demonstrated and evaluated globally. It has functioned on the streets of Moscow, across the great expanse of the Australian outback, and in numerous congested U.S. cities. Several systems now exist and are available for further demonstration and evaluation.

5. TRIAL OBJECTIVES IN AUSTRALIA

The overall goal of the trial in Australia is to demonstrate ATMS in the field as part of an actual shipment. The ATMS system will monitor and track a transportainer from the Olympic Dam mine to Rotterdam, Holland, over land and sea. The Olympic Dam mine site, situated several kilometers from the township of Roxby Downs, SA, Australia, lies in the arid mid-north of South Australia. This mine site is approximately 520 kilometers northwest of Adelaide, SA. From a satellite communications perspective, there is unobstructed satellite horizon on the route between the mine site and Adelaide.

Phase I consisted of the pre-trial activities, primarily on-site visits and evaluations. Phase II and Phase III consist of the design, fabrication, and testing of the ATMS system prior to the trial. Phase IV is the actual trial itself.

Currently, UOC is packed in drums and loaded into International Standard (ISO) shipping transportainers (see Figure 6). The transportainers are placed onto flatbed trailers and transported in a convoy of up to 10 or more vehicles to Port Adelaide, with a total shipment of up to 20 or so

Figure 6. Container Packing Plant

transportainers in one trip. Generally, these shipments occur once every three months. The corresponding road transports are timed to meet the cargo ship at the port for the sea voyage to Rotterdam. The transportainers are then unloaded at the port from the flatbed trailers to the cargo ship.

5.1 Pre-Trial Objectives and Results

Prior to the field trial, site visits were conducted at the involved mines, vehicle transport facilities, and shipping ports in Australia for several important reasons:

1. To acquire mine, trucking, and shipping operator "buy-in" to the overall concept and to provide assurance that the trial would be non-intrusive. This objective was accomplished with full and enthusiastic support from the Olympic Dam authorities, the road transport operators, and the shipping operators.
2. To analyze the logistical needs for such a trial.

All involved sites and activities were visited, logistically analyzed, and documented (with photos, screen captures, and notes).

3. To verify ATMS INMARSAT-C communication and tracking capabilities within Australia. ATMS hardware was successfully utilized to monitor and track simulated shipments through all of the ground-based, mine-to-port transport routes that would be required in the upcoming trial.
4. To determine the appropriate ATMS sensor suite (AIMS-based) and configuration for such a trial. After consultation with all participants, an appropriate sensor suite was determined to be transportainer-mounted active seals (AFOs), door sensors, and a limited set of environmental sensors (temperature, smoke, etc.).

The on-site visit resulted in a positive test of the TDU at SNL in Albuquerque, New Mexico. The SNL-based team successfully tracked the simulated shipment in near-real-time. Three screen displays are shown in Figures 7, 8, and 9.

Through briefings, tours, demonstrations, and

Figure 7. View of the Australian Continent

Figure 8. Regional View of the Transport Route

Figure 9. Street-level Shipment Tracking

logistical meetings at every major point of the shipping process, the on-site team gained a firm understanding of the needs for the trial.

5.2 Trial Considerations

There are certain physical and logistical constraints imposed on the trial by the very nature of the shipment and the agencies responsible for the shipment. Because the trial accompanies an actual shipment, the trial must minimize its impact on the shipping process. Although most of the details of this complex trial have been determined, some information is still difficult to acquire and, therefore, some assumptions have been made.

Because personnel will not have access to the interior of the shipment transportainer for the installation of the ATMS equipment, particular attention and care will be taken to protect the exterior mounted equipment from exposure to the expected weather and handling environments on both the land and sea portions.

The majority of the ATMS platform equipment will be mounted to the exterior of the transportainer for the overland portion of the shipment. For the sea portion, the transportainer may be located outside on the deck of the ship, which will minimize any reconfiguration of associated equipment. However, it is more likely that the container will be located in the hold of the ship, which could require a different physical layout of the system. The design will accommodate all scenarios through the use of RF transmission and cable separation flexibility.

A rechargeable battery system will be the main

source of power throughout the trial. A specially built regulator/charger/supply will be provided to maintain the battery charge. The battery will be continuously charging whenever the controller is connected to the externally supplied power, as will be the case for both the land and sea portions of the trial. (The on-line system will provide power for approximately 3 hours without an external source.)

5.3 System Design

One mobile ground station will be located at SNL in Albuquerque and the other at ASO headquarters in Canberra, Australia.

Figure 10 shows the desired placement of the system components for the overland portion of the shipment. The main ATMS housing will be attached to the trailer and the input charging power connected to the tractor power source. (The ATMS universal power system can handle a large variety of input power sources, both AC and DC.) The RF sensor receiver and the INMARSAT satellite antenna will be fixed to the top of the transportainer. The RF sensor packs will also be attached to the top of the transportainer at the same end as the container loading doors.

Figure 11 shows the expected configuration for the sea portion of the shipment. In this case, the cable lengths from the RPU and the CCU may need to be extended so that the CCU can be located closer to the satellite antenna on the ship's deck.

Appropriate SNL and ASO personnel will travel to Canberra and install the ATMS equipment for the ground station at that location. Static functional tests will then be performed.

Figure 10. Truck System Components

Figure 11. Sea Vessel System Components

Personnel will then travel to the Adelaide Port and the ATMS system for the mobile asset will be installed on either a truck or an automobile for dynamic pre-trial testing. This ATMS-equipped vehicle will then proceed to the Olympic Dam mine, checking operation of all system components along the way. At the mine, the ATMS equipment will be transferred to the transportainer and a static check will be performed.

The full-scale trial will then proceed from the Olympic Dam site for an expected period of several weeks. After the transportainer is loaded onto the ship, the ATMS system will be reinstalled and reconfigured, if necessary, and readied for the sea portion. A representative from SNL may accompany the transportainer and ATMS system throughout the shipment cycle.

The system will be installed to be weather-resistant and modular for easy maintenance and adaptation to each mode of transport. The sensors will be used to gauge internal and external temperature of the transportainer, measure system voltage, and detect door open/closure.

5.4 Trial Timeframe

Phase I and Phase II have been completed. The final system design and configuration are in process. The actual field trial is scheduled to occur in the latter part of 1997 or early 1998.

6. SUMMARY AND CONCLUSIONS

The success of the field trial in Australia will be invaluable to the future development of ATMS. When fully developed and deployed, the ATMS will provide a worldwide capability to track and monitor virtually any type of selected high-value item. The system incorporates sensors, electronics, and tamper-resistant technologies, including encrypted and authenticated messages and robust tamper-indicating enclosures. The system is mobile, battery-powered, and survivable in environmental conditions commensurate with its anticipated use. The trial described in this paper is limited to tracking and monitoring of proliferation-sensitive items; however, the ATMS has a very broad spectrum of potential future applications.