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Review. Monitoring the intermodal, refrigerated transport of fruit using sensor networks

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Abstract

Most of the fruit in Europe is transported by road, but the saturation of the major arteries, the increased demand for freight transport, and environmental concerns all indicate there is a need to change this means of transport. A combination of transport modes using universal containers is one of the solutions proposed: this is known as intermodal transport. Tracking the transport of fruit in reefer containers along the supply chain is the means by which product quality can be guaranteed. The integration of emerging information technologies can now provide real-time status updates. This paper reviews the literature and the latest technologies in this area as part of a national project. Particular emphasis is placed on multiplexed digital communication technologies and wireless sensor networks.

Additional key words: CANbus, container, fruit quality, multidistributed, reefer, wireless.

Resumen

Revisión. Supervisión de transportes intermodales de frutas mediante redes de sensores

La calidad de los productos hortofrutícolas adquiere cada día más importancia. En la Unión Europea la mayor parte de la fruta es transportada en camiones, pero la congestión de la principales carreteras, el aumento de la demanda de transporte de mercancías, estimado en un 38% para los próximos 10 años, y los problemas medioambientales que de ello se derivan hacen necesario modificar los procedimientos de transporte. El transporte intermodal puede ser preciso, flexible y más respetuoso con el medio ambiente. Para asegurar la calidad de las frutas es imprescindible realizar un seguimiento y garantizar la trazabilidad de las mismas durante su transporte a lo largo de la cadena de suministro. Un sistema que integre diferentes tecnologías emergentes puede informar en tiempo real del estado de la carga. Este artículo hace una revisión de las últimas publicaciones y tecnologías aparecidas y recoge una propuesta de desarrollo de una red de sensores en un contenedor frigorífico mediante redes inalámbricas de sensores, buses de campo y sensores inteligentes. También se expone una propuesta de especificaciones para un sistema de supervisión multidistribuido de frutas y hortalizas mediante diferentes sensores y dispositivos electrónicos.

Palabras clave adicionales: calidad de la fruta, CANbus, contenedor, multidistribuido, redes inalámbricas, supervisión.

Introduction

The European Union (EU) is the second largest exporter and the foremost importer of fruit and vegetables. Increasing demand for out-of-season products reinforces the need for long distance transportation; 44% of all goods in the EU are transported by road (Eurostat, 2006). Wholesalers prefer lorry transport because of its flexibility and the possibility of providing door-to-door service. However this medium increases road congestion and the traffic death toll. A solution might be the combined use of all means of transport: road, rail, inland waterways, and short-distance sea shipping (EC, 2001; Gustafsson, 2004).

There are some 1 million refrigerated road vehicles and 400,000 container units worldwide, and the annual value of transported goods is around US$1,200 billion (Billiard, 2002). Quality control and the monitoring of the transport of goods and delivery services are of increasing concern to producers, suppliers, transport

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decision-makers and consumers. This is particularly true with respect to the refrigerated transport industry, where the major challenge is to ensure a continuous «cold chain» from producer to consumer in order to guarantee the prime condition of the goods received (Claridge *et al.*, 2004).

The cold chain, from harvest to the consumer's plate, should be understood as a single entity. Improving one link in the cold chain is not enough to improve the entire structure: an overall approach taking into account energy consumption and compliance with the temperatures required to preserve foods is required. Much control, measurement and monitoring work remains to be done in this area (Coulomb, 2005).

Although goods transport systems have improved in recent decades, they are not yet sufficiently integrated to meet today's requirements in terms of quality and safety, due to the lack of well structured and organized intermodal transport chains (Giannopoulos, 2004). Information technology (IT), incorporating communications technology, could become a primary tool in ensuring the safe and efficient operation of freight transport systems (Giannopoulos, 2004).

The growth in trade, changes in business practices, and safety concerns, have also underscored the need for government-industry partnerships to standardise information exchange and to implement best practices across the global supply chain network. Recently, safety issues have become a major concern. Major goals are therefore to provide support for risk and vulnerability assessments for all interested parties, and to determine ways of monitoring the movement of goods and containers (ECMT, 2002; Wolfe, 2002).

The aim of the present article is to review the technical and scientific state of the art of intelligent monitoring systems for freight transport, including the types of refrigerated containers available, traceability issues, vehicle location technologies, the IT systems available (wired and wireless), and radio frequency identification.

Intermodal freight transport

Intermodal freight transport means the movement of goods in a cargo unit by successive modes of transport with no handling of the goods themselves during changes in transport modes (ECMT-UNECE, 1997). The term «intermodality» should be distinguished from «multimodality». Multimodality only means using different transport methods, while intermodality identifies the integration of shipments across modes of transport but involving only a single administrative process and shipment rate. It is characterised by the transferability of the transported items between modes and a unique system of administration and billing (Short, 2002).

However, intermodal freight service only accounts for some 5-7% of the total tonnage transported; this highlights the difficulties that exist in encouraging shippers to make use of it. One of the major disincentives for using intermodal freight transport has been the low quality of service provided. If intermodal transport is to become a feasible alternative to road transport, it will have to be just as efficient (Giannopoulos, 2004; Gustafsson, 2004). Improving transport efficiency is possible through the development, deployment and use of intelligent transport systems based on advanced information and communications technologies (EC, 2001).

To improve the interoperability and the compatibility of systems, the wide adoption of a common freight transport system architecture is needed. A common approach will enhance development of new applications. In addition, increasing standardisation in the intermodal chain optimises costs (Bontekoning *et al.,* 2004; Giannopoulos, 2004). In this context, there is a need for data exchange standards. Intermodal process flow maps show at least 63 data hand-off points that still include paper, and while there are two widely used electronic data interchange standards, though they do not fully interoperate. Activities are underway, however, for the development of industry-based data standards which are coordinated by ISO. Some of these activities reflect the awareness of the need for safety and security-related data elements (Wolfe, 2002).

Refrigerated containers. Reefers

There are two basic types of refrigerated container (reefer): the porthole and integral type. Porthole refrigerated containers, also known as insulated or conair containers, do not have their own refrigeration unit and relay on an external supply of cold air. Integral refrigerated containers, however, have their own integrated refrigeration unit. This is generally electrically powered and involves a three-phase electric power supply. Integral refrigerated containers are most widely used for fruit transport according to ISO 1496, and are thus the focus of the present study (ISO1496, 1991; GDV, 2005).

Refrigerated ISO containers are commonly named according to their length in feet: 20', 40', and 40' high cube containers (ISO 668, 1988). Even a brief period of equipment malfunction may cause irreversible damage to the goods stored inside; thus, the container storage temperature must be strictly maintained. This requires continuous monitoring of the temperature and the functioning of the entire cooling system (Chutatape, 1989).

The EU subscribes to all the international conventions on the carriage of perishable goods which may be applicable to frozen or chilled products. All member states of the EU and the European Commission (EC) are parties to the ATP agreement (an agreement on the international carriage of perishable foodstuff and on the special equipment to be used for such carriage; see http://www.unece.org/trans/main/wp11/atp.html). Discussion on and the amendment of the ATP agreement take place under the auspices of the United Nations Economic Commission for Europe. The provisions of this agreement are binding on the members of the Community (UNECE, 2003). Legislation EN 12830 (1999) demands class one temperature measurement for fruit and vegetable transport; measurement has to be feasible within the range –25ºC to +15ºC with an accuracy ± 1ºC and a resolution ≤ 0.5ºC.

Tracking, tracing and monitoring

Traceability facilitates the following of foods and provides all operators of the supply chain with accurate information concerning the products involved. Tracking is defined as the gathering and management of information related to the current location of products or delivery items, whereas tracing refers to the retention of the manufacturing and distribution history of products and components. Monitoring refers to the ongoing assessment of the progress of transport by means of continuous or repeated measurement and evaluation (Van Hoek, 2002).

New EU requirements in traceability (in force since 1 January 2005) cover all food and feed and affect all business operators, without prejudice to existing legislation on specific sectors such as beef, fish and genetically modified organisms, etc. Importers are required to identify the producer and the country of origin. Unless specific provisions for further traceability exist, the requirement for traceability is limited to ensuring that businesses are able to identify the immediate supplier of a product along with the immediate subsequent recipient (with the exemption of retailers to final consumers) (EC, 2002, 2004).

A food business operator must register and keep the information required by the EC (EC, 2004). Information technology provides tools for helping transport companies track and trace from the origin to the end of the supply chain; this is particularly important in the area of refrigerated fruit transport. The most effective way for a food company to see that a third-party transport company has done its job correctly is to monitor the transport of fruits in the vehicle – independently of the transport company (Maxwell and Williamson, 2002).

An electronic remote monitoring system for recording the temperature in refrigerated containers is now a standard requirement. ISO 10368 documents the two variants for power cable transmission (PCT) systems: narrowband and broadband transmissions. Narrowband operates at a fixed modulated frequency to send data via the power supply system. In broadband transmissions, data is transmitted over a frequency spectrum ranging from 140 to 400 kHz. Problems arise, however, when the controllers of refrigeration units and the data loggers in use have different ranges of functions and data formats. A third type of remote monitoring system for reefer containers involves a four wire cable used to record the status messages «Compressor running», «Defrost» and «Temperature in Range». Around 80-90% of all refrigerated containers have a socket to connect them to this type of monitoring system. It is expected that transmission will shift from cable-based to radiofrequency wireless data networks in the near future (ISO 10368, 1992; GDV, 2005).

The monitoring system has to operate independently of the refrigeration system since if the electronics of the latter fail, the monitoring system has to remain operational (Maxwell and Williamson, 2002). The use of standards in the digital communications between container electronic monitoring systems and the different intermodal platforms would allow the use of fewer wires and connections, improving system features and fault tolerance. Information provided by a variety of sensors could be used to improve overall monitoring (Ruiz-Garcia *et al.*, 2005).

Vehicle location systems

Electronic monitoring of the location of vehicles during transport can be achieved by two methods: automatic vehicle identification and the global positioning systems (GPS). The former involves the detection of the conveyance at various critical waypoints along its normal route. This is rather inexpensive and involves a relatively small number of active systems reporting to a central data processing site. The time elapsed between waypoints can be monitored for compliance with regard to expected travel times, though problems can arise if a vehicle has to change its normal route (Transcore, 2003).

The most extended GPS system is the NAVSTAR-GPS (navigation system with time and ranging-global positioning system) system developed and maintained by the US Department of Defence and the US Department of Transportation. This transmits at two microwave frequencies, 1,575.2 MHz (L1) and 1,227.70 MHz (L2). L1 is the standard position service, and a combination of L1 and L2 allows the precise code for military or authorised users. NAVSTAR-GPS coexists with the Russian GLONASS (*Globaluaya Navigatisionnaya Sputnikovaya Sistema*) system; Europe is developing its own system known as «Galileo», which is expected to be completely operative in 2010. However, for the location of containers, the accuracy, availability and integrity of these stand-alone systems is insufficient. To obtain the required performance, augmentation systems are used such as the EGNOS (European Geostationary Navigation Overlay Service) or LAAS (Local Area Augmentation System) systems (Lechner and Baumann, 2000).

GPS is currently integrated with the RFID (Radio Frequency Identification) system in order to locate the position of ships and the containers they carry. The system has drawbacks, however, including limited coverage in the more remote parts of the world, signal blockage when containers are stored, a dependence on batteries, reliance on human intervention, and the need for extensive maintenance. The limitation of remote area coverage is the main drawback preventing GPS from tracking individual container positions on land. However, its area of coverage is increasing and efforts are being made to promote the system's flexibility (Balog *et al.,* 2005).

The loss of the GPS signal can be detected via a failure to report to the central data processing site as expected. Systems can be set to automatically alert operators of suspicious disappearances, as well as deviations from the expected route, unscheduled stops, and excessive travel times (Transcore, 2003).

Fieldbus networks

A fieldbus is a digital communications network designed to connect together all kinds of sensors, actuators, transducers, programmable controllers and data processing equipment, within a coherent system. Each field device executes simple functions on its own, such as diagnostics, control, and maintenance functions, as well as providing bi-directional communication capabilities based on a layered structure derived from the seven-layer open system interconnection (OSI) model (ISO 7498-1, 1994).

In comparison with the conventional centralised system, fieldbus technology has the advantages of flexibility, reduced cabling, support cable redundancy, a shorter download time, easy upgrade and on-line expansion, a guaranteed response time, multi-vendor interoperability, and easier and faster design/installation (Hanzalek and Pacha, 1998; Tovar, 1999). Field area networks are used in a variety of application domains: industrial and process automation, building automation, automotive and railway applications, aircraft control, and the control of electrical substations, etc. A few fieldbus systems have evolved into *de facto* standards, the most important being AS-I, Ethernet, WorldFIP, Profibus, Interbus, P-Net and CANbus (Fig. 1) (CENELEC, 1996). Of these, CAN (controller area network)-based systems (Fig. 2) are the basis for road vehicle systems (SAE 1939 and ISO 11992) and for ships (NMEA 2000). Only SAE J1939, ISO 11992 and NMEA 2000 are therefore reviewed in this paper, together with the necessary gateways.

SAE J1939

The SAE J1939 application profile defines CAN-based in-vehicle communications for trucks and buses. It was developed by the American Society of Automotive Engineers (SAE). A J1939 network connects electronic control units (ECU) with a truck or trailer system. SAE J1939 specifies, for example how to read and write data, but also how to calibrate certain subsystems. The maximum bus length of SAE J1939 is 40 m, with a maximum number of 30 nodes and a data rate of about 250 kbps, i.e., 1850 messages per second (SAE J1939, 2000; Johannsson *et al.,* 2003).

Other industries have adopted the general J1939 communication functions, in particular the J1939/21 and J1939/31 protocol definitions, which are required

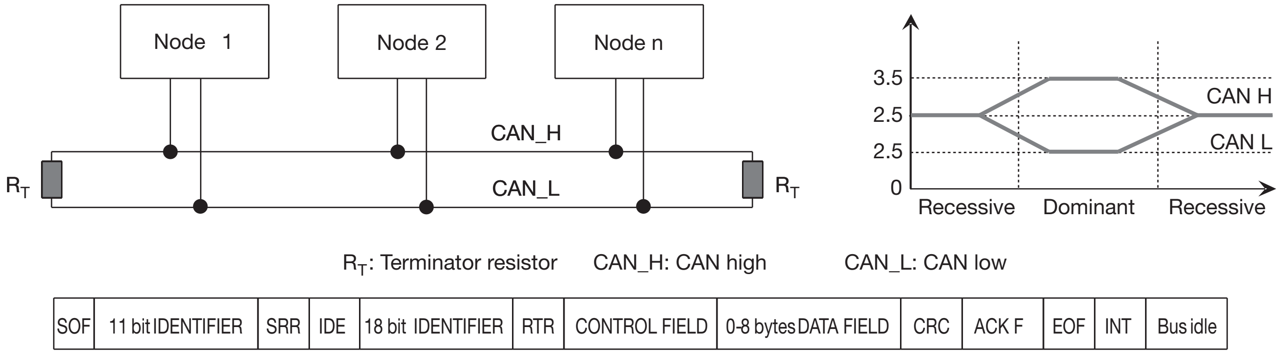

Figure 1. CANbus topology, physical layer and message frame for standard format. SOF: start of frame. SRR: substitute remote request. IDE: identifier extension bit. RTR: remote transmission request. CRC: cyclic redundancy checks. ACK F: acknowledgement field. EOF: end of frame. INT: interframe space.

for any J1939 compatible system. Figure 2 summarizes the international standards based on CAN and J1939 which are used within a variety of transportation domains, including marine applications and on- and off-road vehicles (agricultural vehicles) (SAE J1939, 2000; Johannsson *et al.*, 2003; CIA, 2005).

ISO 11992

The ISO 11992 road vehicles standard (interchange of digital information on electrical connections between towing and towed vehicles) presently consists of four parts: 1) the physical layer and data link layer, 2) the application layer for brakes and running gear, 3) the application layer for equipment other than brakes and running gear, and 4) diagnostics. This standard specifies a J1939-based application profile for the communication between truck and trailer. The ISO 11992 standard is also suitable for road trains with multiple trailers (up to five). The towing vehicle assigns addresses to the towed vehicles (ISO 11992, 2003).

NMEA 2000

This is an open standard based on CAN for serial-data networking of marine electronic devices. NMEA 2000 is harmonized with SAE J1939 and specifies how data are placed into CAN frames, independent of the processor type involved (NMEA, 2000).

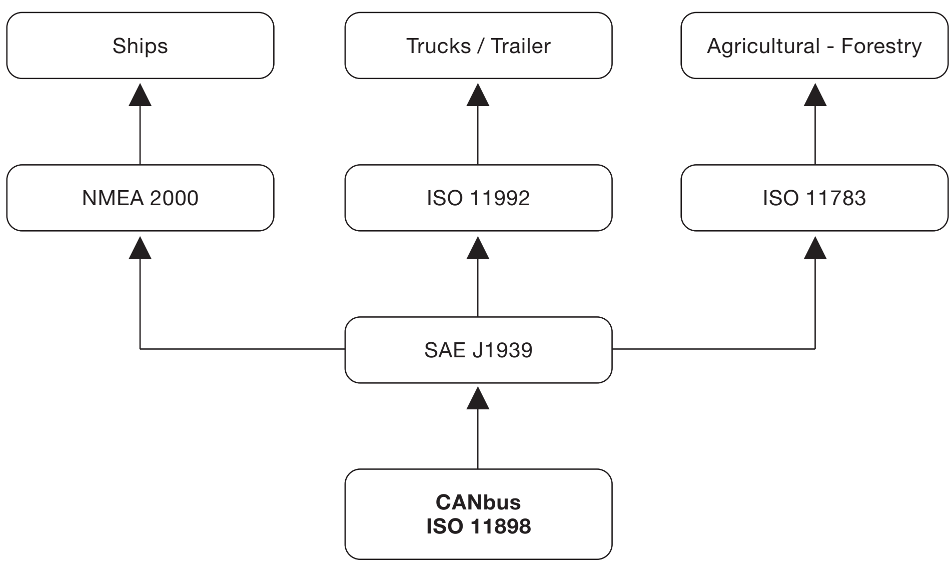

Figure 2. Evolution of CANbus standards.

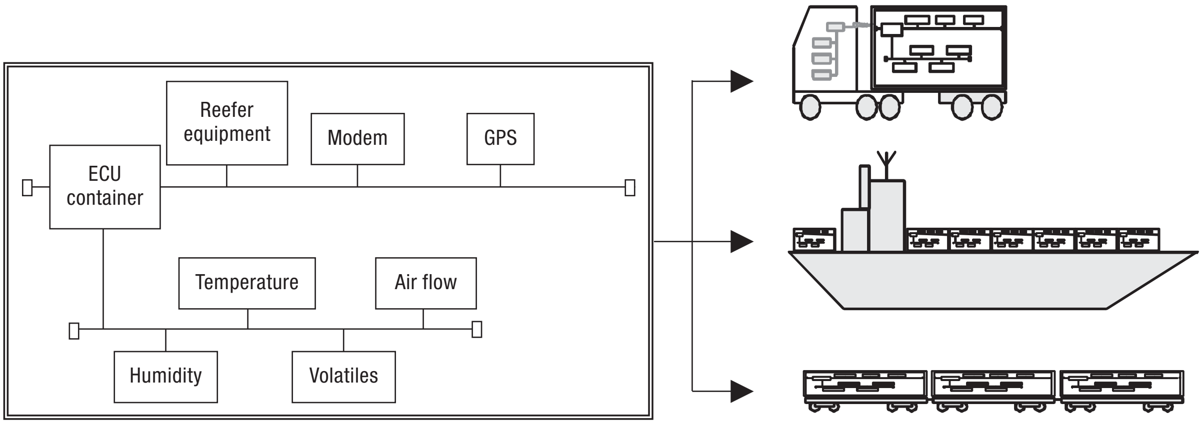

Figure 3. Container controller area network in intermodal transport.

CAN gateways

Gateways are a type of unit for network interconnection and enable CAN-based networks to be linked together or linked to networks using other protocols; this feature can be used in the intermodal transport line (see Fig. 3).

Many types of CAN gateways exist. A special interest group is working on the development and maintenance of a CANopen gateway profile for trucks. This includes gateways to ISO 11992, SAE J1939, ISO 11783 and, in a more specific way, defines the CANopen application profile for truck mounted refrigerators, connecting sensors, actuators and temperature controllers (CIA, 2005). There are both CAN-RS232 and CAN-TCP/IP gateways. The latter can provide remote access to a CAN through the internet, which allows worldwide monitoring and maintenance (Johannsson *et al.,* 2003).

Wireless communications

There are several ways of achieving wireless communications for intermodal transport (see Fig. 4) –wireless

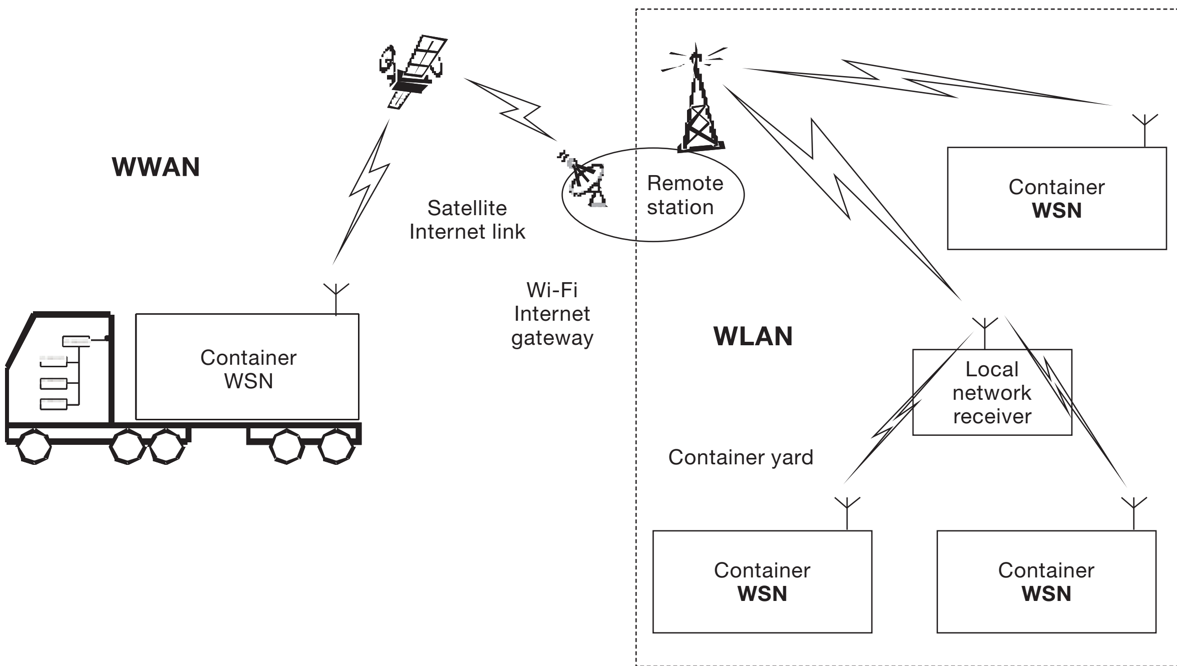

Figure 4. WWANs, WLANs and WSNs in intermodal transport.

Table 1. The most important wireless networks solutions

Name	Implementations
WWAN (Wireless Wide Area Network)	GSM (Global System for Mobile-Communication) CDMA (Code Division Multiple Access) GPRS (General Packet Radio Service) UMTS (3G) (Universal Mobile Telecommunications System)
WLAN (Wireless Local Area Network)	IEEE 802.11.x HyperLAN Home RF
WSN (Wireless Sensor Networks)	Bluetooth Zigbee

wide area network (WWAN), wireless local area networks (WLAN), and wireless sensor network (WSN) systems. Table 1 summarizes the most important standards for wireless networks.

Wireless wide area networks

Wide area networks enable long-range communication between containers and central servers, and are facilitated by satellite and cellular systems. Satellite systems are quite expensive compared to cellular systems, but they provide virtually ubiquitous coverage, so they can relay status messages and GPS data from nearly anywhere in the world. Satellite messaging systems are used in developing regions that lack a cellular infrastructure (ABI Research, 2004).

The use of satellites for monitoring refrigerated containers generally fails when the container antennas become shadowed, rendering data transmission impossible. The same applies when containers are stowed under a deck. In the future, however, it will definitely be possible to send data via satellite from ships to receiving stations on land, enabling online access to the refrigerated containers being transported. Cellular devices make use of surface antennas for transmission (GDV, 2005).

Global System for Mobile-Communication (GSM) and General Packet Radio Service (GPRS) modems are widely used in commercial vehicle tracking and fleet management. Recently 3G technologies have emerged. 3G is a wireless industry term for a collection of international standards and technologies aimed at improving the performance of mobile wireless networks. 3G wireless services offer data packaging enhancements such increased speeds and the capacity for combined voice and data services with high quality service facilities. The two main 3G technologies are UMTS (Universal Mobile Telecommunications System) and CDMA2000 (Code Division Multiple Access 2000). UMTS is a good option for container tracking, as nearly ubiquitous coverage is available in Europe (Baghaei and Hunt, 2004).

Wireless local area networks

Local area networks provide intermediate range data transfer at ports, on marine vessels, and in container yards and terminals; Wi-Fi (wireless-fidelity) is the most important standard.

Wi-Fi is a set of product compatibility standards for WLANs based on IEEE 802.11.x specifications (Wi-Fi, 2005). The 802.11 family currently handles six over-the-air modulation techniques. Those widely accepted techniques include the b, a, and g systems. The 802.11b and 802.11g standards use the 2.4 GHz band, and the 802.11a standard uses the 5 GHz band (IEEE, 1999, 1999 bis, 2003 bis).

Wi-Fi already has a role in locating assets in industrial yards, such as heavy equipment and cranes. Wi-Fi enables RFID (radio frequency identification) readers, handheld or fixed, for data storage and verification (Wherenet, 2003).

When wireless sensor units are installed in containers they communicate with the outside world. The network topology used for system deployment is critical. For example, if the ever-present star (hub and spoke) topology exemplified by most 802.11 (Wi-Fi) networks is used, each wireless sensor node must be able to communicate directly with the base station. Radio link performance for each node is characterized by point-to-point radio communication between the nodes and base station. Classic communication theory (and reality) dictates that when the attenuation present in the node-base station channel increases due to distance or because of a cargo that absorbs some of the RF signal-system, performance will be reduced unless the transmission power is increased. However, this consumes more of the battery, thereby decreasing the system's lifetime (Fuhr and Lau, 2005).

Wireless sensor networks

A WSN is a system comprised of radio frequency (RF) transceivers, sensors, microcontrollers and power sources (Wang *et al.,* 2006). Recent advances in wireless sensor networking technology have led to the development of low cost, low power, multifunctional sensor nodes (as indicated in Fig. 5). Sensor nodes enable environment sensing together with data processing. They are able to network with other sensors systems and exchange data with external users.

Sensor networks are used for a variety of applications, including wireless data acquisition, machine/building monitoring and maintenance, in smart buildings and on highways, environmental monitoring, site security, automated on-site tracking of expensive materials, safety management, and in many other areas (Akyildiz *et al.,* 2002).

A general WSN protocol consists of the application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane, and the task management plane (Qingshan *et al.,* 2004).

Each sensor communicates with a gateway unit which can communicate with other computers via other networks (Wang *et al.*, 2006), such as a LAN, WLAN, WSN, the internet or a CAN. These devices could be the basis for multidistributed systems for monitoring refrigerated containers.

A radio transmission medium, such as that provided by the industrial scientific and medical (ISM) bands, is increasingly used for WSNs. Table 1 summarizes the standards for wireless networks. The main advantages of using the ISM bands, such as the 2.4 GHz band, are that they are license-free, have a huge spectrum allocation, and are globally available (Akyildiz *et al.,* 2002; Qingshan *et al.,* 2004; Wang *et al.,* 2006).

Wireless sensor technology allows micro-electro-mechanical systems sensors (MEMS) to be integrated with signal conditioning and radio units to form «motes» – all for an extremely low cost, a small size, and a low power requirement (see Fig. 5). Available MEMS include inertial, pressure, temperature, humidity, strain-gage, and various piezo and capacitive transducers for proximity, position, velocity, acceleration and vibration monitoring. These sensors can be placed in vehicles in order to monitor the «on-the-go» environment (Wang *et al.*, 2006).

Multi-hop communication over the ISM band might well be possible in WSNs since it consumes less power

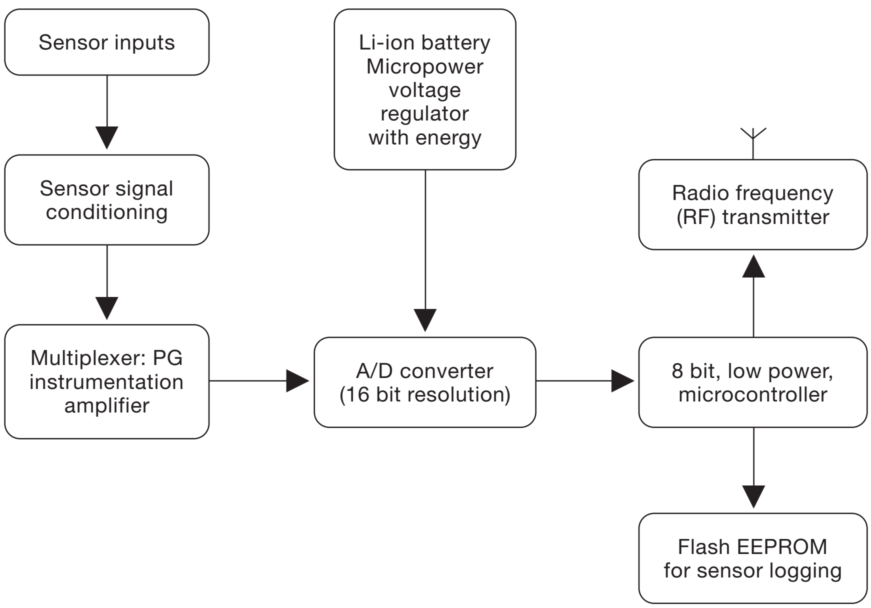

Figure 5. Wireless sensing node.

than traditional single hop communication (Akyildiz *et al.,* 2002; Qingshan *et al.,* 2004). The latest multi-hop communication technologies are Bluetooth and Zigbee.

Bluetooth

Bluetooth (IEEE 802.15.1) is a wireless protocol for short-range communication or wireless PANs (personal area networks); it is a cable replacement for mobile devices. It uses the 868 and 915 MHz and the 2.4 GHz radio bands to communicate at 1 Mb per second between up to eight devices (see Table 2). Bluetooth is mainly designed to maximize *ad hoc* networking functionality. Some of its common functions are passing and synchronizing data, e.g., between a PDA (personal digital assistant) and a computer, wireless access to LANs, and connection to the internet. It uses frequency-hopping spread-spectrum (FHSS) communication, which transmits data over different frequencies at different time intervals. Bluetooth uses a master-slave-based MAC (medium access control) protocol (IEEE, 2002; Dursch *et al.,* 2004; Bluetooth, 2005).

Applications for accessing the internet have been investigated in experiments at indoor hot-spots (Kraemer and Schwander, 2002). An analysis of Bluetooth's role in global 3G wireless communication is provided by Erasala and Yen (2002). Miorandi and Vitturi (2005) proposed implementing Bluetooth-based connections between industrial devices running the Profibus DP protocol. Cena *et al.* (2005) analysed Bluetooth as a possible solution for in-car digital communications. Murari and Lotto (2003) studied the use of Bluetooth in data transmission from vacuum chambers.

Zigbee

The IEEE 802.15.4 standard is a physical radio specification that provides low data rate connectivity among relatively simple devices that consume minimal power and which typically connect over short distances. It is ideal for monitoring, control, automation, sensing and tracking applications for the home, medical and industrial environments (IEEE, 2003).

Zigbee provides reliable, cost-effective, low-power, wirelessly-networked monitoring and control based on an open global standard (Adams, 2003). It targets home building control, automation, security, consumer electronics, PC peripherals, medical monitoring and toys. These applications require a technology that offers long battery life, reliability, automatic or semiautomatic installation, the ability to easily add or remove network nodes, signals that can pass through walls and ceilings, and a low system cost (Qingshan *et al.,* 2004).

Due to the relatively short time that has elapsed since the introduction of Zigbee, no published applications yet exist. However, Zigbee is likely to be very important in WSNs in the coming years (Callaway, 2004).

Bluetooth vs. *Zigbee*

Table 2 provides a comparison between Zigbee and Bluetooth. For applications where higher data rates are

Table 2. Comparison between Wi-Fi, Bluetooth and Zigbee

	Wi-Fi	**Bluetooth**	**Zigbee**
Standards	IEEE 802.11.x	IEEE 802.15.1	IEEE 802.15.4
Data rate	11 to 54 Mb s^{-1}	1 Mb s^{-1}	10-115 kb s^{-1}
Latency (time to establish a new link)	< 3 s	< 10 s	30 ms
Frequencies	2.4 and 5 GHz bands	2.4 GHz	2.4 GHz
No. of nodes	> 100	8	65,000
Range	100 m	8 m (Class II, III) to 100 m (Class I)	10-75 m
Modulation	DSSS[1] and OFDM[2]	FHSS[3]	DSSS[1]
Network topology	Star-access point	*Ad hoc* piconets	*Ad hoc,* star, mesh
Data type	Video, audio, graphics, pictures, files	Audio, graphics, pictures, files	Small data packet
Battery life	Hours	1 week	> 1 year
Extendibility	Roaming possible	No	Yes

[1] DSSS: Direct Sequence Spread Spectrum. [2] OFDM: Orthogonal Frequency Division Multiplexing. [3] FHSS: Frequency Hopped Spread Spectrum.

important, Bluetooth clearly has the advantage since it can support a wider range of traffic types than Zigbee (Baker, 2005). However, the power consumption in a sensor network is of primary importance – and it should be extremely low (Qingshan *et al.,* 2004). Bluetooth is probably the closest peer to WSNs, but its power consumption has been of secondary importance in its design. Bluetooth is therefore not suitable for applications that require ultra-low power consumption; turning on and off consumes a great deal of energy (Shih *et al.,* 2001). Cordeiro *et al.* (2005) have proposed a new design for reducing power consumption for Bluetooth WPANs. In contrast, the Zigbee protocol places primary importance on power management; it was developed for low power consumption and years of battery life. Thus, Zigbee is more suitable for WSNs (Qingshan *et al.,* 2004).

Radio frequency identification

Radio frequency identification (RFID) is an emerging technology that makes use of wireless communication, and in recent years it has been increasingly used in logistics and supply chain management. RFID technology can identify, categorize, and manage the flow of goods and information along a supply chain and provides automatic vehicle and equipment identification. The system is made up of three components: a remote device called the tag, a reader and a host interface (Transcore, 2003; Finkenzeller, 2004).

RFID has the ability to allow energy to penetrate certain goods and to read a tag that is not visible. It can therefore identify goods without scanning a barcode. There are many distinct protocols used in the various RFID systems, some using the lower end of the spectrum (135 kHz) and others using the super high frequency (SHF) end (5.875 GHz). Multimodal shipping containers use tags operating at 433 MHz or 2.45 GHz (Finkenzeller, 2004; Dobkin and Wandinger, 2005).

Given the increasing demand for security and safety, complete documentation for food products from field to customer has become increasingly demanding (Thysen, 2000). RFID is recognised as able to provide well-structured traceability systems for data collection, and human, animal and product tracking (Sahin *et al.,* 2002). It is projected that the RFID applications will grow rapidly over the next 10 years with a compounded annual revenue growth rate in the period 2003 to 2010 of 32.2% (Sangani, 2004).

A promising application of RFID is in electronic seals for containers. The tags can have onboard memory that can be written by means of hand-held and/or roadside/rail-side readers. The container ID is the most common piece of data stored in such seals. Some seals also record the date and time of tamper and/or authorized entry and reseal events. Some also have external interfaces that can communicate with other on-board sensors inside the container for greater security (Transcore, 2003). ISO 18185 (Freight containers - Electronic seals) refers to passive tags and active tags (ISO, 2006).

Recent IT applications for transport

In recent years, much international research has focused on the development of an intelligent transport system. Most of these systems have involved human or freight transport. For the latter, a number of supply chain monitor and tracking tools have been developed, although most devices focus on non-intermodal transport (Gustafsson, 2004). Table 3 summarizes recent IT applications for transport.

Doyle (2003) developed a system for tracking the movement of cargo trailers. A GPS unit provides the location and velocity of the trailer, and a wheel rotation sensor provides the wheel rotation status. Wireless radio communication equipment transmits the trailer movement and wheel information data to a central station. With this information a computer determines the intermodal movement status of the trailer.

Brosius (2005) has proposed a multi-mode asset tracking and monitoring system that combines a WLAN for monitoring crowded environments (such as onboard a ship) and a WWAN that provides coverage in more dispersed environments. Both networks report events from sensors and tags located in the container.

Ng and Wells (2004) patented a method and apparatus for securing and/or tracking cargo containers. The security unit comprises a controller and a positioning receiver (this can be a GPS receiver). The controller can be wired or be wirelessly connected to a light sensor, pressure sensor, toxin sensor, vibration sensor, radioactivity sensor, and/or an intrusion sensor.

Carson (2003) developed a computerized system for tracking the real-time locations of shipping containers. In this case a dispatcher workstation with a graphical user interface and a database is proposed. A mobile unit in the yard is attached to the container handling

Table 3. Summary of recent ICT (Information and Communication Technology) applications in transport

Category	Subject	References
GPS, GSM	Monitoring animals during transport	Geers *et al.,* 1998; Gebresenbet *et al.,* 2003
WSN, GPS	Tracking and monitoring nuclear materials	Schoeneman *et al.,* 2000
WorldFIP	Remote monitoring of nuclear materials	Funk *et al.,* 2000
Bluetooth	Link between truck and trailer	Gunnarsson, 2001
RFID	Automatic identification in rail transport	AAR, 2002; Transcore, 2003
GPS	Intermodal movement status monitoring systems	Doyle, 2003
GPS, WLAN	Container tracking systems	Carson, 2003
RFID	Automatic container identification	Transcore, 2003
RFID	Tracking containers	Karkkainen, 2003
RFID	Electronic seals	Jensen *et al.,* 2003
WWAN, GPS, GIS	Tracking and monitoring containers worldwide	Unnold, 2004
GPS, WSN	Securing and/or tracking cargo containers	Ng and Wells, 2004
Zigbee	WSNs in refrigerated vehicles	Qingshan *et al.,* 2004
WSN	Tracking system for containers in ports	Callaway, 2004
WLAN, WWAN, RFID	System and method for asset tracking and monitoring	Brosius, 2005
RFID	RFID tags in container depots	Ngai *et al.,* 2007
RFID, GPS, Sensors	Integrated tracking, seal and sensor systems	Balog *et al.,* 2005
WLAN, WSN	Smart container monitoring systems	Auerbach *et al.,* 2005
RFID	Monitoring electronic container seals	Kafry and Inbar, 2005
Zigbee	Mesh-network in cargo containers	Fuhr and Lau, 2005
RFID, WSN	«Smart packing», improve traceability	Wang *et al.,* 2006
RFID, WSN	Autonomous sensor systems in logistics	Jedermann *et al.,* 2006

equipment and monitors the container lock-on mechanism. A radio link between the container handling equipment, the container, and the base enables transmission of the real-time position whenever a container is locked onto, moved, or released.

Unnold (2004) developed a system for tracking and monitoring containers worldwide that uses solar cells, rechargeable batteries, two-way satellite communication, a central processing unit (CPU), a variety of sensors, GPS, and a geographic information system (GIS). The apparatus is permanently mounted on the cargo container.

Auerbach *et al.* (2005) focused on the development of a «smart container monitoring system» comprising sensors mounted within the shipping container that wirelessly transmit information to an electronic seal mounted on the outside of the container. Moreover, this seal wirelessly transmits information on its status to a remote monitor.

Kafry and Inbar (2005) proposed a system for monitoring the electronic sealing of cargo containers during their transport along highways. This involves a wide network of readers mounted along highways, and electronic seal transponders installed in vehicles and containers. The readers and electronic seal transponders communicate by means of a standardized protocol. The transponders incorporate a unit that analyses and transmits their status to a control centre.

WSNs have been used for the tracking and monitoring of nuclear materials as part of the authenticated tracking and monitor system (ATMS) (Schoeneman *et al.,* 2000). The ATMS employs wireless sensors in shipping containers to monitor the state of their contents. The sensors transmit wirelessly to a mobile processing unit, connected to both a GPS and an International Maritime Satellite (INMARSAT) transceiver.

Gunnarsson (2001) initiated the development of a wireless link between truck and trailer using Bluetooth. The truck uses a SAE J1939 CANbus while the trailer makes use of an ISO 11992 CANbus.

Qingshan *et al.* (2004) undertook the development of an intelligent WSN for refrigerated vehicles. Zigbee was considered the most appropriate standard for a WSN within refrigerated vehicles in which artificial intelligence plays a key role. The sensors are enhanced with self-calibration, self-compensation and self-validation.

Fuhr and Lau (2005) have shown that a radio frequency device can be placed in a metal cargo container and that it can still reliably communicate with the outside world. They developed a mesh-network in the 2.4 GHz region, using the 802.15.4 protocol (Zigbee).

Callaway (2004) proposed a tracking system for shipping containers in large ports involving WSNs. Sensors on each container disclose their location.

Funk *et al.* (2000) developed a remote monitoring system for nuclear material safety. Abnormal events are detected by smart sensors. Sensor interconnection is achieved by means of WorldFIP. The remote supervision station uses a PC running Windows NT.

Geers *et al.* (1998) and Gebresenbet *et al.* (2003) investigated the improvement of animal welfare during handling and transport. In this case, an on-road monitoring system was proposed. A GPS provides the location of the vehicle, while sensors installed in the animal compartment identify the animals and monitor the air-quality, vibration and animal behaviour. A GSM allows on-line data transmission.

When combined with wireless sensors, the RFID system also enables environmental monitoring as well as the monitoring of specific product quality/safety attributes along the supply chain (Wang *et al.,* 2006).

The US and Canadian rail industry make use of the S-918 standard of the Association of American Railroads for RFID in railcars. This standard allows «*the automatic electronic identification of equipment used in rail transportation, such as railcars, locomotives, intermodal vehicles and end-of-train devices*». Over 5.2 million railcar tags and 12 thousand reader sites are in use (AAR, 2002; Transcore, 2003).

In the USA, Matson Intermodal uses the RFID standard for obtaining automatic container identification in all its operations. As domestic shippers, this enterprise operates within a closed system involving 20,000 containers using one passive transponder (battery assisted) per container (35$ each). Twenty four reader locations at the company's facilities are used to read out information from the identifiers (Transcore, 2003).

Karkkainen (2003) discussed the potential of RFID technology in increasing the efficiency of the supply chain for short shelf life products. He concluded that when RFID is used in recyclable transport containers, investments can be quickly recovered and a range of operational benefits obtained.

Ngai *et al.* (2007) developed a system prototype that gathers mobile RFID applications within container depots. RFID tags are attached to the containers, and readers are installed in the container depot. Besides the identification of containers, the RFID prototype system tracks the containers and assigns them a location.

At the Northwest International Trade Corridor and Border Crossing (USA), RFID transponders have been used in freight management. Technologies include container seals to detect and identify the containers as well as a system that detects and electronically identifies previously registered vehicles (Jensen *et al.,* 2003).

Balog *et al.* (2005) proposed a modular technology involving a GPS locater, RFID tags on pallets, and electronic seals and sensors. The sensors can detect intrusion, chemicals, radiation, vibrations, changes in light, temperature and humidity, thus ensuring that goods are not unknowingly tampered with during transport.

Jedermann *et al.* (2006) described an autonomous sensor system for intelligent containers combining WSNs and RFID. The proposal includes a miniaturized high-resolution gas chromatography apparatus for measuring ethylene.

Conclusions

Intermodal transport may be a solution for goods transport in the immediate future. Intermodal transport, however, needs to be efficient and easy to use. Certainly, the lack of standardization has delayed the adoption of electronic intermodal monitoring solutions for transport containers. A high level global concept of the need for standardization of the entire process is essential. Electronic international freight data exchange standards need to be developed to streamline cargo transactions, improve mobility and security, and reduce costs.

The combination of available information technologies such as CAN, GPS and wireless data communications can provide complete monitoring information about fruits and vegetables transported in reefers containers. They also allow compliance with the legal requirements of food traceability.

The number of recent IT applications published shows that research into intelligent transport systems is an emerging field fuelled by advances in technologies and worldwide concerns about security and food safety, and the concept of the «smart container» is now coming to the fore. The technologies now available make the development of a standard monitoring system for reefer containers feasible. The system should comprise multiple types of sensor in various locations in the container. Critical variables will be supervised by multiplexed communications systems. Authorized supply chain participants will track a container's progress as it journeys from the loading to the unloading point.

Logistics personnel will obtain this information from the information network and can use it for planning supply, processing and transport.

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