



GLOBAL CONNECT PROJECT

<CASE OF USE>

**< TRACEABILITY SYSTEM OF TEMPERATURE,
RELATIVE HUMIDITY AND CARBON DIOXIDE IN CONTAINERS,
AND ITS SCALABILITY>**

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ABSTRACT

The World Bank forecasts global economic growth in the next years, as the recovery in investment, manufacturing, and trade continues, and as commodity-exporting developing economies benefit from stable commodity prices. The world commerce is increasing in complexity because of its size and cost. Studies show that more than 4 billion of US dollars of products are sent yearly and more than 80 percent of the goods consumed daily are transported by sea. The World Economic Forum indicates that a world of rapid technological change and digitalization, trade policy must evolve to empower new forms of digital commerce and reduce barriers that hold back growth opportunities.

One of the requirements is to define and implement a framework for steering and shaping policy developments related to e-commerce, digitalization of trade and cross-border data flows nationally, regionally and globally. Additionally the cost of commercial documentation for a physical transport reaches one fifth of the total cost of transportation. Then the reduction of these barriers could increase 15% the world commerce, boosting economies and creating jobs among some studied estimations. The project goal is to increase the cross-border flow of data of cargo containers transported globally increasing the reliability and lowering the cost of the data collected, to help companies to move and track goods in digital form across international borders.

With such sights, Innotel Comunicaciones AB with a seat in Gothenburg, Sweden and Paradigma Ltd., in Santiago de Chile, have embarked on the "*Global Connect*" project, which is a platform that makes the tracking of maritime containers more reliable and profitable with technologies unique and innovative of both companies.

GLOSSARY OF TERMS

OTT. Over The Top

TMS. Traveling Messaging System

Router ABC. Always Best Connected

CO2. Carbon Dioxide

O2. Oxygen

GPS. Global Positioning System

CTS. Container Tracking Service

LPWAN. Low-Power Wide-area Network

IoT. Internet of Things

M2M. Machine to Machine

API. Application Programming Interface

DSNS. Domain Sensor Name Server

TEU. Twenty-foot Equivalent Unit

DESCRIBING THE CONTEXT

In the Cargo Tracking market 1.3 million units will be remote tracking with GPRS or satellite communication system during 2018, it is estimated that shipments of remote tracking systems with cellular or satellite communication capabilities for cargo loading units including trailers, intermodal containers, air freight cargo containers, cargo boxes and pallets reached 0.8 million units worldwide in 2015. Growing at a compound annual growth rate of 25.0 percent, the shipments are expected to reach 2.3 million units in 2020. During the same period, the installed base of remote tracking systems is forecasted to grow at a compound annual growth rate of 23.2 percent from 2.9 million units at the end of 2015 to 8.1 million units by 2020. Innotel's definition of a real-time tracking solution is a system that incorporates data logging,

satellite positioning and data communication to a backoffice application. Trailer tracking can be part of fleet management solutions including both trucks and trailers. Our aim is to have 100 000 containers connected with Global Connect during 2022. Seaco Global, Maersk and Scenker are all potential customers.

A matter of scalability. Cargo ships are getting bigger.

One aspect to consider: Container ships are getting bigger, and the quantity of stacked containers could hinder the telephone communication of the sensors. We have the following ratio of container quantity per vessel type, TEUs and number of container rows:

- The maximum beam or maximum width of a Panamax-type vessel is 32.31 meters, this corresponds to a capacity of about 2,800 TEU to 5,000 TEU maximum. This is a boat of approximately 294.1 meters of length and 32.31 meters of beam, that is with 12 rows of containers on deck.
- Post-Panamax ships are those with a beam greater than 32.3 meters.
- The Post Panamax I vessels from 1988 onwards have 40 meters of beam, this is 16 rows of containers on deck, with a capacity of 4,000 to 6,000 TEU.
- The Post Panamax II ships from the year 2000 onwards have 43 meters of beam, this is 17 rows of containers on deck, with a capacity of 6,000 to 8,500 TEU.
- The vessels New Panamax or Neo-Panamax (NPX) of the year 2014 have 49 meters of beam, this is 19 rows of containers on deck, and 366 meters of length (22 bays) with a capacity of 12,000 to 14,500 TEU.
- Above 49 meters of beam, container ships are considered ULCV vessels in English Ultra Large Container Vessel, which means Ultra Large Container Ship, which have a capacity of more than 14,500 TEU.
- The Post Panamax III or "Super Post Panamax" vessels from the year 2006 onwards have 56 meters of beam, this is 22 rows of containers on deck, with a capacity of 11,000 to 15,000 TEU. An example of this type of boat is the Emma Maersk (Mærsk Class E boat) with 56 meters of beam, 22 rows of containers on deck.
- The ships of the Triple E class of the Mærsk shipping company from the year 2011 onwards have 59 meters of beam, this is 23 rows of containers on deck, with a capacity of 18,340 TEU.
- An example of this type of vessel is the Triple E Class vessel named Mærsk Mc-Kinney Møller that has 59 meters of beam, although now the Maersk competing shipping companies have bought similar size boats such as the following:
 - the MSC Oscar with 395.4 meters of length, 59.08 meters of beam, and a capacity of 19,224 TEU,
 - the CSCL Globe with 58.73 meters of beam and
 - the ship delivered in March 2017 and named MOL Triumph with 400 meters of length, 58.8 meters of beam, that is 23 rows of containers on deck and with a capacity of 20,150 TEU.
- The Post Panamax III and Triple E ships are considered "Post New Panamax" or "Post Neo Panamax" vessels because they are larger than the specifications of the Panama Canal extended in 2016. Although in reality, even a 50-meter-long ship manga, that is to say with 20 rows of containers on deck, can already be considered as "Post New Panamax" or "Post Neo Panamax", because it exceeds the width allowed by the new dimensions of the Panama Canal.
- As far as we can see, one of the differences between a 14,000 TEU vessel and a 19,000 TEU vessel is the difference in its beam (52 meters versus 59 meters), which means that the 14,000 TEU vessel can have 20 rows of containers on deck, while the 19,000 TEU can have 23 rows of containers on deck.
- There are even larger vessel designs on the design boards, such as the "Malacca Max" class that could carry around 27,000 to 30,000 TEUs, but they are not expected to be built in this decade.

- In both the year 2017 and the beginning of 2018, the Orient Overseas Container Line (OOCL) has progressively presented its six new containerships belonging to the G-Class series (OOCL Hong Kong, OOCL Germany, OOCL Japan, OOCL Scandinavia, OOCL United Kingdom and OOCL Indonesia), which have become the largest in the world thanks to their nominal capacity of 21,413 TEU.
- The Triple E, a class of 400-meter long container vessels that will carry as much as eight Eiffel towers and have a capacity equivalent to 18,000 containers.

Analysis of the transmission capacity from a container

Trying to understand the real situation of transmission during the transport of containers it was found that when it is done with trucks the proposal works well. But during the transport of containers in a ship a restriction is foreseen. The restriction refers as the containers are stacked, and there is no control over where they will be stacked. The ships can have between 500 and 18,000 containers as shown in the following images.

We do not have the assurance of transmission during the shipment, due to high possibility of getting the signals blocked when it tries to reach a satellite or mobile telephony operator, especially in the containers inside the pile or inside the ship.

In view of this problem, and thinking about the scalability of the solution and the market, an study was made to solve the problem, and made some changes in order to be sure that the solution was scalable.

The proposed extended solution consists of two extra elements:

- **Gateways.** They receive the transmissions made by multiple end devices and forward them to the network servers.
- **DSNS server (Domain Sensor Name Server).** Responsible for the reception and processing of the information that comes from the final devices, as well as the management and configuration of the network and the final devices.

The solution consists of a star-on-star network topology, which uses sensors that send data captured through gateways, using the LPWPAN protocol, with the interaction of a DSNS Server.

The network formed by the final devices and the gateways is star type with a single jump (from Gateway to Server). This type of networks is very easy to implement and manage (as routing elements are not necessary). In addition, the gateways, not acting as routers, do not retransmit traffic from other gateways with the consequent energy savings. Simplicity and energy saving are essential requirements in the IoT implementation networks.

In summary, devices in the network are asynchronous and transmit when they have data available to send, and it has not been able to communicate by mobile or satellite telephony. Data transmitted by an end-node device is received by gateways, which forward the data packets to a centralized network server. The network server filters duplicate packets, performs security checks, and manages the network. Then, the data is then forwarded to server TMS.

USE CASE: TRACEABILITY OF TEMPERATURE, RELATIVE HUMIDITY AND CARBON DIOXIDE

Let's see the following example: The most important elements to consider in the transport of perishable foods such as fruit and vegetables is the follow-up of the following indicators:

Temperature is one of the most important factors because it can cause irreversible damage. Not all products admit the same temperature, but those that do tolerate it, can be transported together. The temperatures for these products are very variable, since there are some products that can be transported at a temperature of up to 15 ° C. On the other hand, those who have more metabolism also need to constantly renew the atmosphere of the camera have to be transported to colder temperatures.

Relative humidity is the amount of water found in the environment in the form of water vapor and is measured as a percentage. Being the maximum, 100% is known as the saturation point. That is to say, that, if these conditions are met, the existence of water vapor would not fit since it has condensed and becomes liquid. The fact that there is a humidity in excess can propitiate the withering of the product. However, a moisture that does not reach the minimum required by the fruits and vegetables causes them to transpire producing a loss of water and therefore a decrease in the life of the product. Regarding the relative humidity in the transport of these products, it should be said that all vegetables require similar humidity, which is around 85% - 90%. On the other hand, there are exceptional cases, such as garlic that needs a less humid atmosphere, between 70 - 75%. Another case is that of lettuces that need a more watery environment (90% - 95%) or the beet needing to reach the point of saturation, 100%. While the fruits need a high relative humidity, close to 90%, as is the case of the grape, peach or orange, strawberry or any tropical fruit being better that exceeds this percentage if possible to 95%. Other fruits such as tangerine, melon or watermelon, its ideal humidity is between 85 - 90%. Finally, mention that nuts require different humidities for their conservation. It may be the case that a relative humidity of around 70% is needed for nuts or if moisture is not required and even the need to vacuum-pack if we talk about peanuts so they do not spoil.

The proper concentration of Carbon Dioxide prolongs the storage life of fruits and vegetables due to inhibition of respiration. The appropriate concentration depends on the species and variety of the product, with adverse effects occurring outside these values. High concentrations of CO₂ can induce physiological disorders in the tissues of fruits and vegetables, such as brown heart in apples and pears.

Duration of Transportation. With the technological advances of today, it is not necessary that transportation occurs too quickly from the moment of its collection. Thanks to the cold rooms where vegetables can be stored for months once they have been harvested at their optimum moment. During transport, this has to be done without breaks, since a breakage of the cold equipment can mean the total or partial loss of the goods. The operations that are carried out around the transport have to be done in a coordinated way, quickly and without interruptions that could cause the merchandise to lose its qualities. As long as the cold chain of fruits and vegetables is not broken, they can be transported at any time, before reaching their maximum shelf life. The transport temperatures and humidities vary with the transit time of the merchandise, that is, it is not the same to transport mangoes harvested from Peru through a reefer equipment than to transport it from Andalusia to any remote point in Europe. Starting from the fact that the duration of the first trip far exceeds the second and therefore for the transoceanic journey you will need more cold so as not to lose qualities during your journey to your final destination.

In this stage of the project IoT and TMS concept tests will be done (the Innotel dataless technology), the InnoTel telecommunications service, SmartCaller, uses the callback without data (during the configuration of the callback, the SmartCaller application connects to a phone number through the InnoTel operator switch and then hangs up (implying a zero cost for the configuration of the call)).

To this end, we will integrate low cost sensors with wireless communication that allows adequate supervision of the load.

For the pilot test will be installed in the containers: temperature sensors, relative humidity, and carbon dioxide. A GPS module for localization, and communication modules for 3G / 4G mobile operators, Satcom satellite telephony, Bluetooth BLE, and a wireless network module LPWAN. Additionally, a flash memory storage system will be implemented in case of no telephone coverage. A DSNS server will be implemented on the container ship. The server will also have the GPS module for the location, and communication modules for 3G / 4G mobile operators, Satcom satellite telephony, and a flash memory storage system in case of no telephone coverage. And two gateways in specific places on the ship.

Two scenarios will be evaluated, the Global Connect Project solution, which indicates that each container has the ability to send captured data from the sensors using the TMS protocol, via satellite or mobile telephony. And an extension to the original solution, consisting of a star network topology, which uses sensors that send captured data through gateways, using the LPWAN protocol, with the interaction of a DSNS server. The server transmits the data through satellite telephony or a mobile operator using the Innotel TMS protocol (there is a call queue), in case of not having coverage, the data is stored in the flash memory, until they achieve adequate coverage and they can be retransmitted.

The sensors are of different categories and send data of different types, such as location, temperature, relative humidity, carbon dioxide. So, this central place should understand which sensor sends data, what is the value of this data and its category.

We have the following categories:

- Category 1: sensor that delivers temperature
- Category 2: relative humidity sensor
- Category 3: carbon dioxide sensor
- Category 4: location sensor (latitude and longitude)

The range of values per sensor is:

- Temperature ($^{\circ}$ C), with values [-50, 50]
- Relative Humidity (%), with values [0,100]
- Carbon dioxide (%), with values [0,100]
- Location (Latitude), with decimal values [-90.90]
- Location (Length), with decimal values [-180,180]

Algorithm to encode sensor data

From the side of the sensors, each sensor must encode in some way the information that you want to transmit to the TMS.

This coding must be done through a list of subsequent telephone calls at the central station (TMS), which then uses this list of calls to decode the information obtained and sent by a sensor.

Our encoding algorithm is based on numerical systems, representing values as list of bits. Since one sensor can emit more than one value and different values can have different length, the number of bits used for some value description will depend from the value itself. For example, longitude, which has approximately 9 digits, can be described with 32 bits, while the relative humidity, which can be a maximum 100 percent, can be described with 8 bits.

There are values with low number of digits and if this is the case, one call only can transmit them. But there are also values with higher number of digits, which need more calls to transmit the value to the central station. Moreover, usually one sensor gives more than one information, for example pollution and humidity. In these circumstances, again we need to make more phone calls. On the other side, these calls should identify themselves to which part of information belong to. Somehow, now that the system reads the call, it should automatically categorize to which part of the information it belongs. Aiming this purpose, we define a new metric named offset, which associates the value with the concrete part of information.

In this line, the transmission contains two parts: the identifying part and the value part. The first bits will be used for the identifier and the next remaining bits will be reserved for the value. The idea behind the identifier now that its value is read, will automatically indicate the position to which that part of the information belongs.

So, we need a function that projects each value depending on its displacement.

Steps for TMS coding

1. As a first step in encoding the source number is its multiplication by 10^x , where x is the number of digits after the decimal place that we want to consider, depending from the number of bits that we want to occupy for that physical measurement. For example, if we have an information that has eight digits after the decimal place, but we want consider only the first six digits, then this number should be multiplied by 1000000. The multiplication constant is predefined for every metric particularly. If there are no digits after the decimal place, the first step is skipped.
2. After the multiplication operation, we take only the integer part of the gained number. If the integer part is positive number, we move to the next step. Otherwise, we negate it using the two's complement logic by adding 2^b , where b is the number of bits used for representation. For example, if 32 bits are used, then number 4294967296 will be added, which is equal to 232. Another possibility is to shift the values from the negative part to the positive part gaining in this way a new range of values that starts from 0. If the range is let say $[-r, p]$, after the shifting, it will become $[0, p + r]$.
3. We convert the result obtained from the previous step to its hexadecimal equivalent. The bytes from this value are separated and used to make a list of phone call to transmit the value. If the phone number range is at most 10000, then the calls will be byte by byte. This means that to every single byte corresponds one single phone call to the central station. Otherwise, if we have more available phone numbers for call, we can make phone calls using two successive bytes.
4. As the last step, the offset is added to each byte returned in the third step of our encoding algorithm, respectively to its position. In this way, if we have slots of 8 bits per physical measurement, then to the first byte is added 0, to the second byte is added 256, to the third byte is added 512, to the fourth 768 and so on.

Example:

Let's take a value equal to -67.7264727 for longitude to illustrate how the encoding/decoding works for a concrete value, supposing that we have used 32 bits for this particular sensor:

Encoding:

1. Since in this case there are 7 digits after the decimal place, we multiply it by 10⁷, which results in -677264727.

2. As $-677264727 < 0$, we calculate the two's complement by adding $232 = 4294967296$, which outputs to 3617702569 .
3. Because the hexadecimal value for 3617702569 is $D7A1C2A9$, the first byte is $D7$, which decimal equivalent is equal to 215 . Processing similarly for all four bytes we get the numbers $215, 161, 194, 169$.
4. We add the identificatory digit to each byte correspondingly and now our list of numbers is $215, 417, 706, 937$ ($215 = 0 + 215, 417 = 161 + 256, 706 = 194 + 512, 937 = 169 + 768$).

Thus, these numbers will be used now to make four calls that end with the just calculated values. The sensor side will make these calls to the central station. Here the calls should be decoded to revert the original value.

Implementation and results

The average time needed to establish call is approximately 5 seconds. Taking that in our case we have available the phone extension ranging from 0000 until 9999 , with one call we can transfer approximately 13.3 bits. From this we can conclude that for this communication channel the capacity is $13.3 \text{ bits} / 5 \text{ sec} = 2.66 \text{ bits/sec}$.

In this way, with 11 calls we have the data of one container (4 calls for longitude, 4 calls for latitude, 1 call for temperature, 1 call for relative humidity and 1 call for carbon dioxide). Totalizing 55 seconds in the case of mobile telephony, 99 seconds in the case of satellite telephony (placing a delta of 4 seconds with respect to mobile telephony).

Table. Measuring the performance time per container by mobile telephony

Measure	Number of Calls	Average time Mobile operator (Sec)	Average time Satellite telephony (Sec)
Length	4	20	36
Latitude	4	20	36
Temperature	1	5	9
Humidity	1	5	9
CO2	1	5	9

The sensor will communicate in the first instance with the mobile operator to transmit the data, if it fails to do so it will be communicated by means of satellite telephony to transmit the data, if it does not succeed because of being without coverage or being very low on the stack of containers, which prevents communication, will transmit the data to the DSNS server through the LPWAN protocol (wireless network) so that the server connects to mobile or satellite telephony, in case the server can not be connected either, the data It will be stored in flash memory waiting for coverage to be transmitted.

The ideal times are the same as the table shown above, however there are limitations that could delay the transmission, these are:

Work Cycle and Collisions. In networks where low-speed transfers prevail, performance is limited by the number of collisions, while in networks where high-speed transfers prevail, performance is limited by the restrictions imposed by the regulations regarding the work cycle (due to the limitation in the number of frames per day that a device can emit).

Numbers of Devices. Another factor that limits the capacity of the network is the number of devices. The increase of devices has a strong impact on the performance of the network.

Distance to the Gateway. A highly scalable network is needed so that with a single gateway it can connect a very high number of devices as long as the speed and capacity requirements are low. Then, in order for network performance to be unaffected, most devices should be close to the gateway, especially those with high traffic. As the number of devices that are far from the gateway increases, the reliability of the network decreases significantly.

Identification and security keys. The unplanned use of surveys can limit the scalability of the network since the gateways are also limited by the restrictions of the work cycle and the continuous issuance of recognition frames can limit the number of frames of orders or data that the gateway can send per day.

The server also has a call queue.

