Combining Machine-to-Machine Communications with Intelligent Objects in Logistics

Javier Palafox-Albarran[1,2], Alexander Dannies[1], Bala Krishna Sanjeeva[1], Walter Lang[1], and Reiner Jedermann[1]

[1] Institute for Microsensors, -actuators and -systems (IMSAS)
University of Bremen, Otto-Hahn-Allee NW1, Bremen, Germany
{jpalafox,adannies,bsanjeev,
wlang,rjedermann}@imsas.uni-bremen.de
[2] International Graduate School for Dynamics in Logistics
University of Bremen, Hochschulring 20, Bremen, Germany
jpalafox@imsas.uni-bremen.de

Abstract. The combination of Machine-to-Machine (M2M) communication and intelligent objects can largely improve the supervision of logistic processes. This requires global mobile communications and short-range wireless sensor nodes. We assembled a demonstrator using off-the-shelf hardware for tests and classroom experiments that shows the feasibility of implementation of the future Internet of Things. It includes the use of embedded devices to perform local intelligent data processing and allows an evaluation of the advantages of ubiquitous M2M communication on a laboratory scale. New software features can be deployed, either to the gateway-device in the form of OSGi-bundles or to the sensor nodes in the form of MIDlet-suites, by using M2M-technology. As an example, we programmed an algorithm for predicting temperature curves in a container using real acquired datasets. A gateway bridges the local and the global network. Sensor messages can be forwarded via email and SMS or be provided by a web server.

Keywords: Internet of Things, Machine-to-Machine Communications, Ubiquitous Computing, Wireless Sensor Networks.

1 Introduction

Machine-to-Machine communication (M2M) is the automatic communication between machines without human interaction allowing direct access to real-time data. One example is a smart meter, which measures the consumption of electricity or water at home or in a factory. It transfers the readings to a remote central system on a daily or hourly basis. The remote system is able to review or act on the collected data. The communication system for transferring data from the remote facility may be, for example, the cellular network and communication satellites. The selection depends on the cost and connection availability. Satellite is the most expensive solution, but is often the only solution in very remote areas or overseas. The solution of cellular

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networks is gaining much attention as it usually fits the best; due to dropping costs of sending data and their wide spread coverage.

Wireless Sensor Networks (WSN), on the other hand, is an emerging technology to monitor ambient conditions. However, they are commonly considered to be stand-alone; the sensor nodes communicate with other sensors and the gateway, but are in principle unable to communicate with the outside world. To change that, the Open Geospatial Consortium [1], is making an effort to establish open geospatial and location standards for exploiting Web-connected sensors and sensor systems.

The combination of M2M and WSN technologies brings the opportunity to profit from their respective advantages. Real world data, collected in the environment, can be integrated into the information world by sending data to the Internet. Furthermore, the system may become ubiquitous, which conceptually means “existing or being everywhere, especially at the same time”.

The research is in an early phase and addresses the integration of both technologies into logistics separately. In the BRIDGE project [2] the existing Electronic Product Code (EPC) network [3] was integrated with the Open Geospatial Consortium (OGC) sensor web enablement architecture [1] to show the benefits of the integration of sensor data in logistics. In [4] Kim and Ryu propose an extension of an RFID middleware for active sensor tags. Aberer in [5] and Jajekyu in [6] also combine concepts of object identification, sensor data and the Internet. In a commercial system called Smart Trace [7] M2M is used as an online cold chain monitoring system where temperature changes inside the container are measured by wireless smart tags and uploaded to a server.

While the focus is put on improving the monitoring of the assets through cold chain, intelligent data processing and remote deployment of new software components are not considered in the mentioned approaches. Information about the cargo, provided by intelligent algorithms, will help a human operator or a machine to take efficient logistics decisions. If such algorithms are required, they must be deployed remotely as access to the cargo is often impossible through the transportation.

This paper presents a lab-demonstrator developed by the Institute for Microsensors, -actuators and -systems (IMSAS) as part of the “Intelligent Container Project” by using only open software. Its intended purpose is using it as a tool for educators, students and researchers to evaluate the impact of M2M communication in food transportation supervision.

As the quality of goods mainly depends on the temperature during transportation, this environmental parameter is chosen for demonstration. It shows the best of both technologies. To demonstrate how sensor nodes communicate between each other and process sensor data locally, an algorithm was implemented, which foresees the final temperature at the end of transport in a refrigerated container transporting perishable goods. The algorithm applies the Feedback-Hammerstein training and prediction algorithms [8] to estimate the parameters of a model describing the temperature changes. The sensors send the actual and future temperature via radio to a gateway which generates a notification either via SMS or e-mail to inform about the current and future conditions.

In most wireless monitoring applications the physical access to the sensor is not an option. Nevertheless, it may be necessary to change the software for data acquisition or data processing during the life-time of the sensor. The demonstrator shows how this challenge can be handled: new software components can be uploaded remotely to the gateway as well as to the sensor nodes.

2 State of the Art

It is hard to find a definition that clearly distinguishes between M2M and WSN technologies. Both technologies can utilize sensors to perform remote monitoring and communicate with each other through wireless communication. Knowing the subtle differences will help to understand the implications of their combined use in logistics.

M2M is a technology that allows communications-enabled remote devices to exchange information automatically without human interaction. The basic four stages according to [9] are: data acquisition or collection, transmission of data through a communication network, assessment of data, and response to available information. In general, local devices with missing or only limited intelligence and computing capabilities are used for data acquisition. Their task is to transmit data periodically or to send alarms when a threshold is exceeded or a malfunction is detected. Data is sent to the telemetric system via wired or wireless communication. The assessment of data and the response to it are made through human interaction due to the fact that the local devices are unable to do it autonomously.

WSN, on the other hand, is an emerging technology to monitor ambient conditions. However, they are commonly considered to be stand-alone; the sensor nodes communicate with other sensors and the gateway, but are in principle unable to communicate with the outside world.

WSNs and wireless M2M devices are equipped with sensors, a radio transceiver, an antenna, processing capabilities and an energy source. However, there are differences: wireless M2M covers applications involving longer range and the node will typically be powered from the machine itself; WSNs consist of several sensors interconnected, usually powered by batteries and cover applications involving shorter range.

M2M are deployed when power consumption is not critical, the size/weight of the devices is not an important factor and a range of kilometres is required. Additional features may include, for example, bidirectional communication.

WSNs are to be deployed in short/medium range areas where human intervention is not possible – either because it is too dangerous, like in a battlefield or a forest fire, or too remote to send people, as is the case when monitoring glaciers and mountains. The system must replace human intervention with spatially distributed sensor nodes. The desired characteristics of an autonomous WSN deployment include high lifetime and robustness as well as fault tolerance and self-configuration [10]. Furthermore, it cooperatively monitors physical or environmental conditions, such as temperature, humidity and pressure, at different locations.

2.1 The SunSPOT as Example Sensor Node

There are several sensor node platforms on the market today available for researchers and students. The most frequently used are TelosB, programmed using a C-like language and TinyOS, and IMote2, which is highly configurable and can run the operating system Linux, with a Java Virtual Machine (JVM) and an OSGi-framework on top of it. However, learning the configuration and getting used to both of them is too time consuming to be used in a demonstrator.

The chosen platform to be used in the demonstrator is the Oracle SunSPOT [11], because both the hard- and software are open source. It is possible to write applications in Java (Java ME), which are platform-independent. Using an Integrated Development Environment (IDE) like NetBeans makes the deployment (with the internal use of ANT-scripts) of new applications very easy.

The core of the SunSPOT is an Atmel AT91SAM9G20 processor running at 400 MHz, integrated with a multichip package consisting of 8MB Flash Memory and a 1MB SRAM memory, power management IC to go to deep-sleep mode, an IEEE 802.15.4 CC2420 chip and an inverted-F antenna printed on the circuit board. The interconnected sensors are: a temperature sensor integrated in the ADC LTC2487, a three axis accelerometer MMA7455L, and an ADJD-S311-CR999 RGB light sensor [8].

The Squawk Java VM is pre-installed on the SunSpot. Squawk is targeted for small resource constrained devices. It utilizes the concept of isolates, where several applications running on the VM can share common suites, leading to a significantly reduced memory footprint and multi-threading. The used Connected Limited Device Configuration (CLDC) only contains the minimum amount of classes necessary to enable the operation of a JVM. The Mobile Information Device Profile (MIDP) allows applications written, the so-called MIDlets, to be used, installed and removed dynamically.

3 The Impact of Combining M2M with WSN in Logistic Practice

In conventional transport logistics it is required to have the right product, in the right quantity, at the right place at the right time. In this context, an instant identification of the assets in the supply chain is helpful, which is possible by reading RFID tags.

It is important to point out that when considering perishable goods, the data management becomes dynamic and the dependence on the previously mentioned requirements becomes stronger. The increase of such dynamic behaviour is conditioned by the quality data, which determines the dynamic of the other aspects. For instance, the right time, quantity and place may vary during the transportation. As the quality of the goods decreases, new routes and suppliers/buyers have to be found, according to the actual price of the cargo, with the aim of increasing the profitability.

At the same time, this quality data is susceptible to fluctuations in environmental parameters, such as relative humidity or temperature. The deteriorations can lead to a decrease in the aesthetic appeal, as well as a reduction in nutritional value. The information about the quality/temperature of the product must be available at any time and everywhere, in order to have valuable information that allows taking proper decisions. As a result, the amount of goods that arrives at the costumer in non-acceptable conditions decreases. This leads to further advantages, such as reduction of transport volume and greenhouse gas emissions. Actions against faulty cooling conditions can be taken as soon as a problem arises. Goods can be sorted in the warehouse by their actual quality condition. It requires the deployment of more sophisticated technologies to include the mentioned dynamic fluctuations in the supply chain.

Combining M2M and WSN in logistic practice has the potential benefit of waste reduction, which is achieved by a greater amount of and more accurate just-in-time information. Well accepted global technical standards, such as EPCglobal [3], that enable instant identification of items in the supply chain may be extended to include management of sensor data. In EPCglobal real objects are linked to the Internet through the use of the unique electronic product code (EPC), such representation of objects in the network is attributable to the Auto-ID centre [12, 13] and is called "The Internet of Things" (IoT).

The EPC standard is based on static data and was conceived as an efficient tool for the traceability of the assets. The cold chain, which is a special case of supply chain, requires, in addition to traceability, environmental data monitoring to provide complete information about quality of the goods. The temperature of frozen and chilled goods must be monitored continuously throughout the entire cold chain.

Uckelmann**,** Harrison and Michahelles [14] defined the Internet of Things from a logistic point of view. As they mention, information about the right condition and at the right price have to be included in addition to traceability. They describe the requirements for the future Internet of Things. In a broader vision, the possibility of including embedded devices such as WSN is mentioned.

M2M and WSN will fill the gap between autonomous logistics and the Internet of Things. M2M will allow us to access information in a ubiquitous way at a reasonable price by sending the right e-mail or SMS with the condition information to be readable for human interaction. WSN may use sensor information to detect signs of degradation of condition at an early stage with the help of intelligent data processing.

4 Concept of the Demonstrator

Fig. 1 displays the concept of the demonstrator. It consists of three categories: WSN, gateway and end-user; in each one of them only open software is used. Conventional remote monitoring is possible by using M2M communication (which is represented by dashed lines in the figure), if the sensor nodes are programmed to transfer the readings periodically to be visualized by the end-user and/or to send and alarm when a temperature threshold is exceeded. However, such a solution may lead to unnecessary data transmission. Our implementation differs to that in running algorithms on the sensor boards to predict the temperature change and shelf life. The task of the WSN is the gathering of environmental data – here temperature values – and local data-processing. The processed data is transferred wirelessly and can be received by the base station – the juncture between the WSN and the gateway.

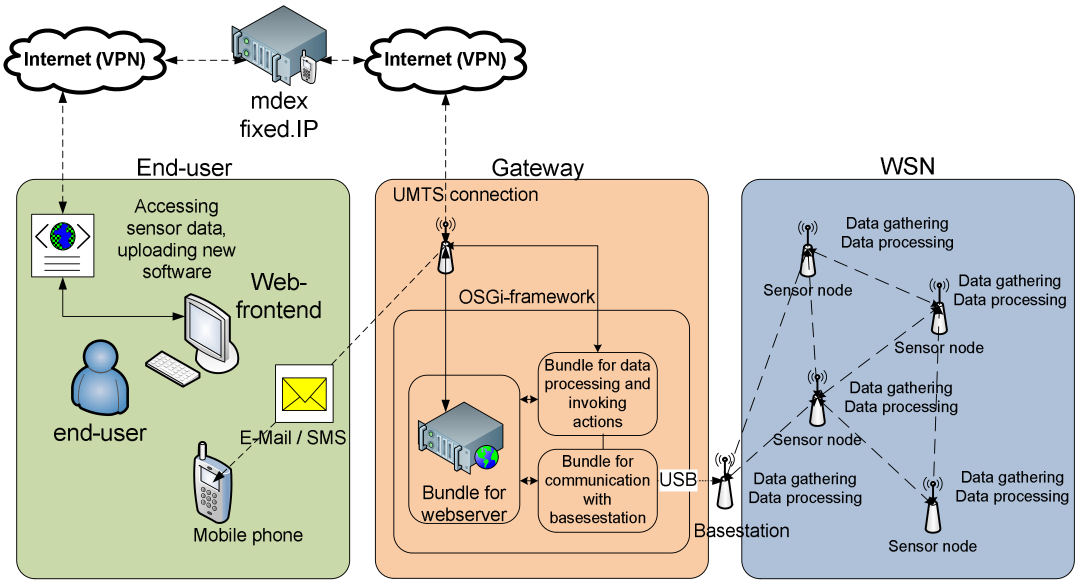

Fig. 1. Concept of the demonstrator (M2M communications represented by dashed lines)

Through the gateway it becomes possible to connect the sensor world with the information world. For this purpose, the Equinox OSGi-framework is installed on top of the Linux OS, which enables a high degree of dynamics by allowing the installing or updating of software modules remotely during runtime. An OSGi-bundle contains a web server and servlets for generating dynamic web-pages – this is for displaying data and altering of software on the sensors. Furthermore, another bundle encloses an implementation for sending notifications via SMS or e-mail. The end-user can decide, if he is notified of selected events, for instance exceedance of a specified temperature threshold; can take a look at gathered data of the WSN; or even has the ability to deploy new software to a chosen sensor node.

From the different types of wireless sensor modules, we selected the SunSPOT because it provides the option to update or deploy new Java applications without physical access to the sensor. One or more applications, so called MIDlets, can be combined to a MIDlet suite and transferred over a radio link to the sensor node.

The currently available example applications for managing a network of SunSPOTs are based on a PC providing graphical interfaces and a human operator. The idea of M2M Deployment goes beyond this concept. Firstly, it should be possible to deploy MIDlets in remote sensor networks without a fixed connection to the internet. In our solution the sensor network is linked by a gateway to a GPRS or UMTS cellular network for global communication. The gateway has only limited recourses compared to a PC and should operate without any local user interface. Secondly, we pursue the vision that machines deploy updated software on other machines. Therefore, the deployment process must be fully automated and executable over multi-modal networks. A backend machine, for example a central server for environmental supervision, decides when it is necessary to update the software of some sensors in the field to perform a new measurement or data evaluation task.

Instead of using a telematics unit with a base station, a GPS/GPRS/UMTS module can directly be connected to the SunSPOT. If the module has very low power consumption, the powering eventually becomes possible via the SunSPOT itself. Otherwise, an external power source for supplying the SunSPOT and this communication module would be necessary. This solution allows all basic functions of the demonstrator except for the remote deployment of new MIDlets.

5 Exemplary Implementation on the Involved Platforms

As an example for a demonstration of how data gathering, intelligent data processing and ubiquitous communication may be applied to improve logistics, the case of transportation of perishable goods is considered.

The goods within a refrigerated container are not exposed to a uniform temperature profile. The temperature distribution within a single container can vary significantly. Temperature deviations of ±2 °C were observed between pallets inside an oversea container loaded with bananas [15]. The temperature profile depends on the ambient temperature, the total air circulation rate and distribution, external environmental conditions, and the respiration heat of the goods. Packing mistakes can either block or short-circuit the circulation of cooling air. In this case, temperature deviations can rise to up to 10 °C.

Sensor nodes are to be co-located within the goods as depicted in Fig. 2. The data of the air supply and on the boxes containing the goods is gathered and processed by the sensor nodes. The processing in this example is made by the node in the box by calculating the parameters of an equivalent model of the refrigerated container. Those parameters are transferred between the sensor node and the gateway. The gateway may send it to a remote server, which can use them to predict future temperatures.

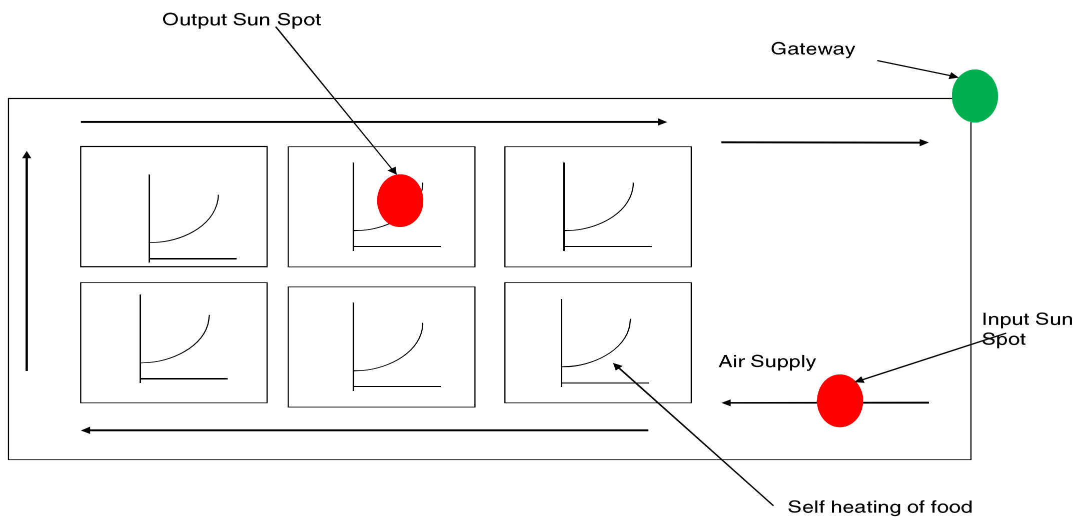

Fig. 2. Implementation of the platforms in a refrigerated container

5.1 Data Gathering

The SunSPOT located near the cold air supply samples the local temperature periodically and broadcasts it to the rest of the sensors located inside the boxes. These sample the local temperature in the boxes every time a measurement from the air supply sensor arrives. For demonstration purposes, the reading from the sensors is replaced by reading an array of floating values containing the resulting datasets from an experiment during a shipment of bananas from Costa Rica to Antwerp in May 2008 [15].

5.2 Data Processing

The future temperature values inside the container can be calculated by using system identification techniques, which estimate the missing parameters for a given model structure. A Single-Input Single-Output (SISO) grey-box model is used to predict the temperature inside the container under the presence of perishable goods with the aim of reducing the complexity and preserving the accuracy. The proposed, so called Feedback-Hammerstein with white noise model, is shown in Fig. 3. It provides a meaningful description of the factors involved in the physical system including the effect of transporting living goods, such as fruits and vegetables.

In order to perform an efficient data processing on the SunSPOT, an online recursive method was chosen, as it requires much lower resources in terms of memory and CPU power than offline counterparts. The difference equation of the model presented in Fig. 3 is described by equation 1.

$$a_1^*(q^{-1})\mathrm{y(t)} = b_1\alpha u(t) + b_1\beta(e^{\gamma y(t)} - \gamma y(t)) \tag{1}$$

In the model, γ is a key parameter that characterizes the heat production in Watts per kg of fruit as a function of temperature. The value of γ depends on the type of fruit, but is constant for all products of the same type. The following parameters have to be estimated: β, which is a scaling factor depending on the amount of food and is given in kilograms, b_1, which is the zero of the first-order linear system and a_1^*, which is the pole of an equivalent pseudo-linear system. The algorithms to calculate the required parameters of the resulting system are presented in [8]; they have lower order matrix dimensions and do not need any matrix inversion. In total, three parameters for the equivalent system are estimated ($a_1^*, b_1\alpha\ and\ b_1\beta$) and are updated after each measurement. The Java-math-library is still not available on JavaME. Required mathematical tools, such as matrix inversion and exponential function, were implemented and tested as additional features and for further expansions of the algorithm . In order to give an accurate prediction, the model parameters have to be iterated over three days at a measurement interval of one hour, equivalent to 72 cycles.

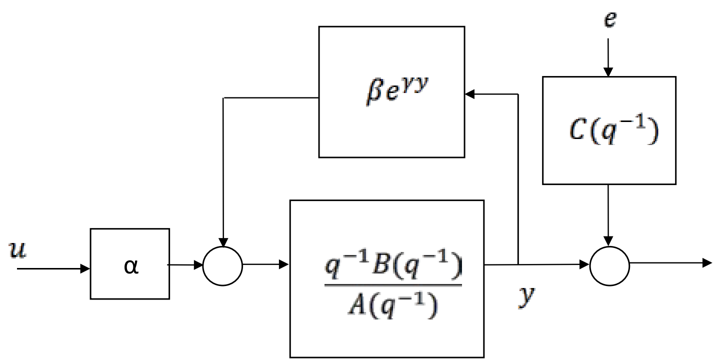

Fig. 3. Feedback-Hammerstein Model

5.3 Data Forwarding

After the data processing in each SunSPOT is performed, the three resulting model parameters and the last supply and output parameters are forwarded to the base station. The base station is connected to the gateway device which provides an OSGi-framework. Different software modules are installed in this environment. One bundle receives data from the base station and also runs a prediction algorithm, which is able to calculate each point of the output temperature profile for the remaining transport duration – typically two weeks. Based on the calculations in correspondence with a defined threshold value, an event can be triggered in the OSGi-context. To be able to react on these events, additional bundles can be installed. One application, which can be connected to the environment, is a web interface for displaying data in form of a table or graph. It can also be used for remote configuration, for instance to change the threshold value for notifications. Other pieces of software can be added to the environment, which send notifications via SMS or e-mail when receiving an event. For sending these notifications, an uplink to a mobile service provider is necessary. For being able to access the provided web interface from around the world, a two-way communication needs to be established. Due to the fact that mobile service providers only assign IPs in the private network address range like 10.x.x.x, a connection to the gateway device can't be established. An extra service is needed to allow that. Here, we choose the gateway provider mdex, which represents the juncture between the two ends: WSN-gateway and end-user. Both ends join a virtual private network at the service and so are able to communicate with each other.

5.4 Deployment of MIDlets over M2M Communication

For enabling an upgrade of the intelligence of the sensors in the WSN, a mechanism for the deployment of new software is necessary. The solution in this context consists of three steps. Firstly, the new Java code has to be compiled and linked, which results in a jar-archive, which is then used to create a MIDlet suite. In the second step, this MIDlet suite has to be transferred to the gateway device, which is connected to the base station. This can be done via an upload dialogue provided by the web interface.

The final step is the execution of a deployment script, which is also accessible via the web-frontend. This script installs the suite on the SunSPOT sensor, which completes the upgrade process.

6 Evaluation and Discussion

Traditionally, logistics is based on traceability for static data. An ID tag is assigned to the goods to know if they are going to arrive to the designated place in the right quantity and time. EPCglobal standards manage such information globally, basically based on RFID tags.

Recently, the necessity of much more interactive and intelligent features has been recognized. They should allow an efficient management of dynamic data as required, for example, during the transport of perishable goods. Sensing, interaction with the environment, mobility and local intelligence are trends for the future Internet of Things, which will optimize the information flow.

The combination of the respective advantages of the technologies RFID, WSN and M2M communication in transport logistics explores a new technical horizon. This leads to a breakthrough in the future Internet of Things, which will allow a global and pervasive traceability of the location and quality state of the assets.

This paper is presented with the aid of a demonstrator showing how the pervasiveness of M2M combined with the embedded intelligence of wireless sensor technologies will impact the management of the dynamic behaviour on food transportation.

Feedback-Hammerstein training and prediction algorithms were used as an example of the intelligent features that can be deployed in wireless sensor nodes. M2M was demonstrated by sending the prediction results from the sensor node to a telemetric system that sends an SMS or an e-mail to be read by a human operator.

The demonstrator was implemented completely using free software. Linux and the OSGi-framework Equinox, with the additional bundles needed in this context, were installed on the Gateway, and Java ME was used for the SunSPOTs. It also demonstrates additional advantages of dynamic updates supported by Java and OSGi by allowing MIDlets that may contain intelligent algorithms required to deal with the actual cargo condition to be deployed remotely onto the sensors in real time.

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