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A Fog Computing Framework for Blackberry Supply Chain Management

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Abstract

With the rapid proliferation of RFID systems in global supply chain management, tracking every object at the individual item level has led to the generation of enormous amount of data that will have to be stored and accessed quickly to make real time decisions. This is especially critical for perishable produce supply chain such as fruits and pharmaceuticals which have enormous value tied up in assets and may become worthless if they are not kept in precisely controlled and cool environments. While Cloud-based RFID solutions are deployed to monitor and track the products from manufacturer to retailer, we argue that Fog Computing is needed to bring efficiency and reduce the wastage experienced in the perishable produce supply chain. This paper investigates in-depth: (i) the application of fog computing in perishable produce supply chain management using blackberry fruit as a case study; and (ii) the data, compute and storage requirements for the fog nodes at each stage of the supply chain. In the process, we discuss the benefits of the proposed fog nodes with respect to monitoring and actuation in the blackberry supply chain.

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Keywords: Radio Frequency Identification (RFID); Blackberry Supply Chain Management; Internet of things (IoT); Fog Computing

1. Introduction

The Internet of Things (IoT) is based on the idea that the physical environment will be seamlessly merged with the virtual environment. One key technology used to realize this is the Radio Frequency Identification (RFID) devices [1]. The most data rich and intensive RFID application is the supply chain management system in which a tagged product is tracked from manufacture to final purchase. Supply chain represents the sequence of organizations involved in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customers. Supply chain management consists of planning, implementing and controlling the operations of the supply

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chain as efficiently as possible.

RFID differentiates itself from the traditional barcode through its possibilities for bulk registration, identification without line of sight, unambiguous identification of each individual object, data storage on the object, and robustness toward environmental influences and destruction[2]. Potential benefits of implementing RFID for the supply chain stakeholders include: obsolescence prevention; counterfeit prevention; decreased inventory; reduced stock-outs; reduced shrinkage by theft; improved asset visibility; and real-time decision making.

Global supply chain scenarios are typically characterized with use cases in which massive amounts of data are collected for processing from myriad geographically dense endpoints. In such cases, storing and analyzing all the data in a centralized, remote data center may be less than optimal for the following reasons. Firstly, the data volume generated by the sensors may exceed the network bandwidth thus introducing delays. Secondly, for latency-sensitive applications, data transmission to a remote cloud would introduce unacceptable delay, especially when the data analysis is designed to trigger a local, real-time response (e.g., automatically alerting the shipping manager when the temperature of perishable produce in transit goes above the optimal temperature). Thirdly, to survive in today's competitive market, retailers need to make it easy for consumers to buy anywhere, receive anywhere, and return anywhere. The key to this cross-channel order promising is the ability, in real-time, to locate and allocate available inventory from any location, whether in the store, in distribution centres, in transit, or on order from the manufacturer. The solution is to do more computing locally, thus reducing the amount of data which needs to be sent to central servers in the cloud. In addition, network and compute resources may need to be configured in a more suitable architecture in which compute resources are split between local sites (where data is temporarily stored as it undergoes preliminary filtering or analytics) and the cloud (where it is further analyzed and stored).

Perishable produce are sensitive to temperature conditions in which they are handled and require special storage conditions in order to preserve their freshness. The variation of temperature arises when items move through supply chain actors (manufacturing, transportation, distribution stages). The freshness of perishable products is tracked by their "lifetime" (also known as Shelf Life). Once an item surpasses its lifetime, it is no longer safe for use. Sensor-enabled RFID tags are deployed to monitor and track the produce from manufacturer to retailer in large-scale applications. We consider the blackberries supply chain. The dynamics of berries supply chain are different compared to other perishable supply chains due to the following reasons: (i) the high respiration rate of the fruit; (ii) the ability to quickly lose water and weight from the lack of a protective peel or rind; and (iii) the need for the fruit to be rapidly cooled and kept cold during the harvest and distribution process since they are highly susceptible to mold and decay[3]. These characteristics make the fruit extremely perishable and therefore strictly regulated climate-controlled environments are needed to maintain the freshness of the fruit. Once harvested, shelf life begins to deteriorate based on the prevailing environmental conditions. For blackberries, the amount of heat produced as a natural consequence of respiration depends on the storage temperature. Therefore, tracking and monitoring the environmental conditions of blackberries from the field to retailer is critical. This can help the grower, distribution manager and retailer calculate the remaining shelf life, identify any potential quality issues and help route produce effectively. For this reason, Fog Computing is proposed.

Fog Computing was first introduced by Cisco in 2012, to describe a compute, storage and network framework for supporting Internet of Things applications. The metaphorical term highlights that compute resources are close to the ground (that is, proximate to the data sources), in contrast to cloud computing, in which compute resources are centralized and remote [4]. The main feature of fog computing is its ability to support applications that require low latency, location awareness and mobility. This ability is made possible by the fact that the fog computing systems are deployed very close to the end users in a widely distributed manner, making it suitable for global supply management. By orchestrating and managing compute and storage resources placed at the edge of the network, fog computing can deal with the ever increasing demand for real time analytics in perishable produce global supply chain management.

We adopt the following approach:

- examine critical time sensitive operations that require local processing at each stage of the supply chain; and
- present a *fog-cloud-based RFID* system framework to address the shortcomings of cloud-based RFID in perishable produce global supply chain.

The text is organized as follows. In Section 2, we describe previous and related works. Section 3 describes the elements of fog computing and how it can enhance the perishable produce supply chain. Section 4 discusses the integration of fog computing into blackberry supply chain. Monitoring and actuations carried out by the fog nodes are also elaborated in this section. Section 5 provides the conclusion.

2. Previous and Related Work

In the case of fresh perishable products, there is a major requirement for precise environment condition monitoring along the complete logistic chain in order to ensure food safety. The supply chain of fresh and perishable foods is characterized by short product lives and fast transportation. Current environment parameter monitoring systems used in perishable produce supply chain include strip chart recorders, temperature data-loggers and time-temperature indicators [5]. They all possess the limitations of having no means to communicate with a reading device to automatically transfer data to an information system and they can only monitor a single parameter (temperature) [6]. Recently, several solutions for implementing temperature managed traceability systems using RFID tags with embedded temperature sensors have been reported [7,8]. One technical challenge is the management of the huge data amount generated from sensors. For this purpose, more attention has been paid to Cloud-based RFID [9,10,11]. Cloud computing provides computing services that are scalable and virtualized [12]. Guinard et al. (2011)[9] explored the application of RFID systems, RESTful interfaces and Web 2.0 mashups for surveillance in retail stores. The authors employed the Electronic Product Code Information Services (EPCIS) using Fosstrak software platform to create the cloud based traceability application. In another study[10], a cloud-based tracking and tracing system for Returnable Transport Items (RTIs) is proposed. The system features Hybrid AutoID process and a cloud repository while adopting the EPC standard. In[11], the design and implementation of an RFID tracking solution based on web services and cloud computing resources was presented. The emphasis was on shifting a greater part of data processing to the readers and cloud resources. To our knowledge, there are no references in literature where fog computing has been applied to perishable produce supply chain management.

Fog computing is an extension of Cloud computing to the edge of the network. It has been designed to support IoT applications, characterized by latency constraints and requirement for mobility and geo-distribution[13]. Similar systems typically known as Edge Computing, such as Cyber Foraging [14], Cloudlets and mobile edge computing[15] date back to early 2000. Fog computing aims at selectively pushing computation closer to where data is produced.

3. Enhancing Perishable Produce Supply Chain with Fog Computing

We propose a perishable produce fog computing model which comprises of 3 layers.

Layers in the Fog Node

- *Layer 0 (Data Producers)*: The data producers include the RFID embedded sensors that produce sensor readings to be consumed by the monitoring and control layer. Data produced by the tags in this stage include the Electronic Product Code (EPC) of the pallet/case monitored, time, temperature, humidity, internal and/or external pressure, vacuum level, air-purity (oxygen, nitrogen, carbon dioxide, and other gases levels), fermenting gas level (such as ethylene), light exposure/brightness, and other environment parameters measured by the sensors.

- *Layer 1 (Monitoring and Control Layer)*: The main responsibility of this layer is to execute control logic (generate actuator command) through analysis of the sensor readings. This involves computing alarms and generating events, which may trigger work-flows through machine-to-machine or human intervention. Fog devices in this stage include: active or smart readers and truck as a mobile-fog-node. These readers are installed at critical way points which include the field, truck, dock doors, and the retail display unit. We will describe the roles and models of each of these components below:

- *Smart Readers as Fog Nodes*: Smart readers not only interrogate the tags but also possess in-built programmable microprocessor with extended processing capabilities. These capabilities include: the ability to store and forward data at specified intervals when network connection is poor, the ability to support business intelligence within the reader and the ability to be configured in order to provide alerts and notifications in the event a device degrades or fails. The system can send an email or SMS message to designated personnel, leading to quick response and resolution when issues arise. This reduces downtime in RFID read zones and eliminates the costs associated with manually recovering missed data transactions. All sensor readings collected by the fog node in this layer are filtered and stored in a temporary buffer, since spurious and repeating reads can be obtained. This process comprises the first processing stage of the system. After filtering, they are aggregated and forwarded to the next fog layer for analysis while ensuring data integrity and authentication. A smart reader can serve as a processing hub for dumb readers that do not have processing capabilities. An example is the Alien ALR-F800[1] new fifth-generation reader architecture that intelligently adapts and configures based on its environment. The readers are connected to other fog nodes via a multitude of interfaces. However, these should be standard open interfaces like USB, Ethernet and PCI and other wireless technologies like GPRS. In terms of network, the RF interface allows for easy communication between reader and tags.

- *Truck as a mobile-fog-node*: This consists of RFID tags, smart readers and the following elements.

  * *Onboard Decision Support Unit (ODSU)*: This is the most intelligent component of the vehicle onboard equipment. The ODSU receives filtered sensor readings from the smart reader and matches them against the produce default temperature and humidity profile. If the parameter values exceed the maximum or fall below the minimum temperature and humidity threshold levels, the ODSU triggers an alarm and issue corrective actions, or perform automatic adjustments.

  * *Event Notification Unit*: The event notification manager is triggered by the ODSU after corrective actions have been carried out in the event of a threshold violation. The Event Notification unit sends alerts in form of messages and emails to the distribution/warehouse manager and the driver.

- *Layer 2 (Cloud Servers)*: The primary responsibility of this layer is to store and analyze the entire history of the supply chain operations that span multiple systems. Data offloaded by the mobile fog node include the history of sensor readings that exceed threshold, the shelf life of the cases/pallets and number of expired pallets. Based on these data, possible computation carried out in this layer involves: (i) determining the amount of produce to be delivered to downstream retail stores/ distribution centers; and (ii) optimal routes at each level of the supply chain.

  The proposed fog computing model is compatible and adaptable to other sectors of the perishable produce supply chain such as blueberry, raspberry, lettuce, fish etc. The hierarchical fog layer is shown in Figure 1:

[1] http://www.alientechnology.com/products/readers/alrf800/

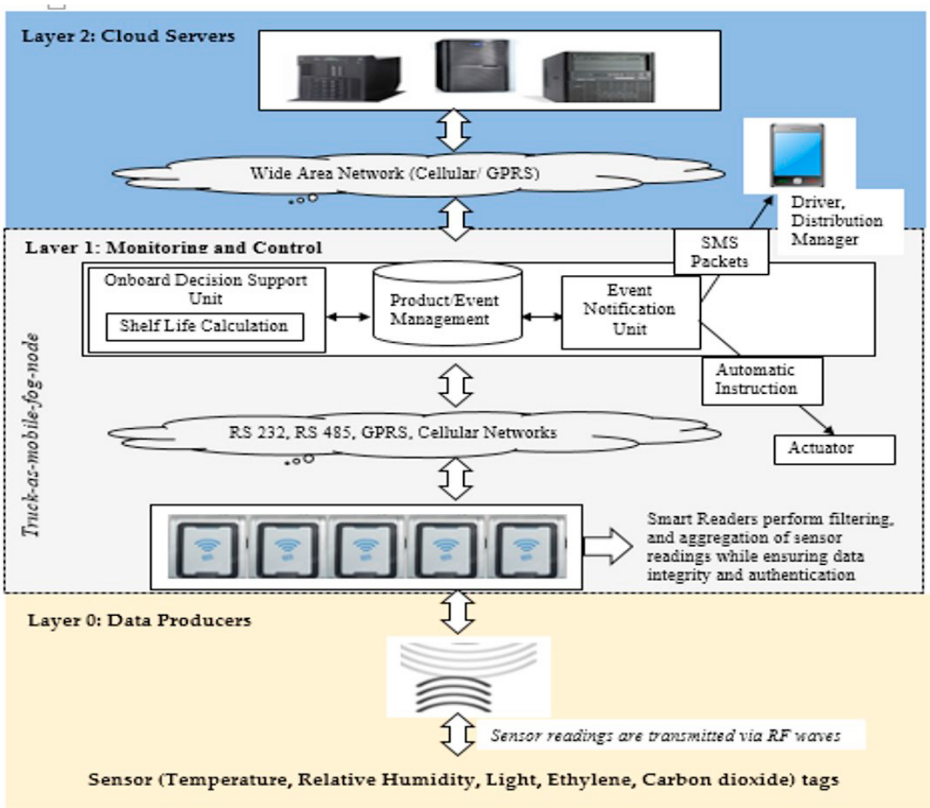

Fig. 1. Fog layers for perishable produce supply chain

4. Integration of Fog to Cloud-based RFID Solution in the Blackberry Supply Chain

4.1. Phase 1

Intelleflex (Now Zest Labs)[2], in conjunction with ProWare Services [3] conducted a case study with an international berry grower with operations in Central Mexico that documented issues and ways to reduce temperature related loss in the cold chain. The project studied two phases in the supply chain: (1) from the field to the packing house in Mexico; and (2) from the packing house to the distribution centers (DC) in the USA [16] The blackberry supply chain process workflow during the first phase is illustrated in Figure 2:

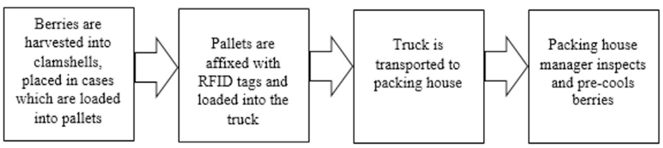

Fig. 2. Phase 1: Blackberry Supply Chain Process Workflow

[2] http://www.zestlabs.com
[3] https://www.prowareservices.com

The Stages are explained below:

- *Harvesting of Berries in the Field*: Blackberries used in the case study had a shelf-life of 17 days under optimal conditions. Maximum shelf life is attained when fruits are held at 0^0C. At 10^0C, shelf life is lost 3 times faster and over 9 times faster at 30^0C [17] . It is therefore extremely important to remove the field heat in the fruit immediately after harvest to lower the respiration and transpiration rates significantly. The produce should be protected from the sun and transported to the pack house quickly using refrigerated trucks. Intelleflex $XC3^{TM}$ semi-passive temperature monitoring tags were placed in the individual pallets of blackberries at harvest in the field in order to monitor the temperature.

- *Transportation of Berries to Packing house*: This is often carried out by semi-trailers/truck equipped with cooling systems or flat-bed trucks. The transit time from the field to the packing house ranges from less than an hour to more than 4 hours. Therefore, it is recommended to use a refrigerated truck that is capable of providing the required cooling and humidity control while in transit.

- *Inspection / Pre-cooling of Berries at the Packing house*: Upon arrival at the packing house, the products are further inspected based on their weight, color and size. Pre-cooling (rapid removal of field heat) is essential to suppress enzymatic degradation, slow respiration, slow or inhibit water loss, and inhibit the growth of decay-producing microorganisms.

Monitoring and Actuation without Fog Nodes

Sensor readings are stored on the tags. No actuations are performed in the field and in-transit. Upon arrival at the pack house, readers are deployed at the receiving dock of the pack house. The readers download the temperature history and upload it to the cloud servers via wireless area networks (local WiFi). Reading full temperature charts from the RFID data loggers at the receiving docks may be slow and this may introduce delay in uploading the data to the cloud. Furthermore, network connection and bandwidth may not be guaranteed introducing further delays. Cloud servers carry out shelf life computation for each pallet and provides a report that shows pallets with shelf life below the required threshold. Based on this information, the field manager groups the pallet for pre-cooling and distribution according to their shelf life. Due to the delayed action, 30% of the pallets suffered from shelf life loss [16].

Monitoring and Actuation with Proposed Fog Nodes

In the Field: Fog nodes deployed in the field can provide real time monitoring of berries. With the local compute and storage resources provided by fog nodes, berries can be monitored on a case level. Also, additional environmental parameters such as relative humidity of the berries can also be recorded by the tags and sent to the fog node for analyses. Major processing performed in this stage is the shelf life estimation of each case based on the time temperature data. Upon reception of sensor values, fog nodes compute shelf-life and if the shelf-life falls below a defined threshold, send a notification to the field manager via his mobile phone. Upon reception of alert, field manager performs immediate loading of the cases/pallets into truck so they can be shipped to the packing house quickly. In other cases, if the berries had been left on the field for too long and their shelf life had expired, the field manager may dispose the berries rather than shipping them to the packing house.

In-transit : The fog nodes used in this stage include the smart readers and the truck as a mobile-fog-node. Sensor embedded RFID tags are also deployed to monitor the refrigerated air to ensure that the ambient temperature of the truck is within the required range. The packing house manager, field manager and the truck driver are alerted about the cases once the shelf-life drops below the reference values. If the berries are expired, they are immediately disposed off and an order is placed to replace the expired stock.

At the Packing House: The data from the fog nodes are used to determine the priority of pallets/cases for pre-cooling and also for shipping to retail distribution center. The benefits provided by fog nodes are the following. Fog nodes eliminate the time delays associated with uploading the data to the cloud. This ensure that pallets/cases are promptly pre-cooled on a First-Expired-First-Out (FEFO) basis. This reduces further degradation of freshness in the berries thus reducing wastage.

4.2. Phase II

In the second phase, the berries are shipped to distribution centers. Controlled atmosphere is usually administered to slow down the respiration process. The environmental parameters to be monitored at this stage include: temperature, humidity, carbon dioxide and light intensity.

Monitoring and Actuation without Fog Nodes: Pallets, with Intelleflex temperature monitoring tags, were loaded into the truck for distribution to the California US distribution centers. This trip takes 4 days. On the pallets, temperature was monitored on a 3-hour basis and saved on the internal memory of the tag. Upon arrival at the distribution centers, the time-temperature history on tags was downloaded and the shelf life for each pallet calculated. The actual pallet-level temperature data, however, demonstrated that there was a wide variation in pallet temperatures within the trailer and therefore shelf life loss while the pallets were in route in the trailer. As a result of the temperature variation inside the pallets in the trailer, 5 pallets experienced temperatures greater than 40^0F resulting in accelerated shelf life loss. The ambient temperature of the truck however remained constant during the trip.

Monitoring and Actuation with Proposed Fog Nodes: With fog nodes, we assume that the truck is equipped with facilities for controlled atmosphere. The conditions necessary to trigger alerts and the necessary adjustments carried out are outlined below:

Table 1. Monitoring and Actuation in Fog Nodes

Parameters monitored by sensors	Conditions to Trigger Alert	Actuation carried out by fog nodes
Temperature	Poor air circulation leading to uneven cooling in the truck	Truck can be diverted to the nearest environmentally controlled facility. Upon arrival, the truck driver checks to see if there are obstructions in the movement of air. If any, they are cleared.
Relative Humidity / Carbon dioxide	Humidity values fall below or exceed threshold values; Carbon dioxide concentrations fall below or exceed threshold values.	Automatic adjustments are carried out by the fog node by reducing/increasing the humidity/carbon dioxide levels to the required levels.
Light	Light intensity exceeds threshold	Truck driver should ensure that the doors are properly shut.

5. Conclusion

The limited shelf-life of perishable goods and their susceptibility to fluctuations in environmental parameters often lead to high loss rates in the perishable produce supply chain. Using the blackberry supply chain as a case study, this paper explores the stages of the supply chain and the monitoring and actuation required. A Fog-Cloud model that can be used to provide seamless quality control in real-time from the field to the distribution centers with emphases on when, where and how fog nodes can be integrated into the blackberry supply chain is described.

Computation to be carried out by the fog nodes include (i) the analysis of temperature data through the Arrhenius law to estimate the shelf-life and the degradation rate of the produce[18,19]; and (ii) the use of the Pearson product moment correlation coefficient to estimate the distribution of air circulation in the truck. The Arrhenius function relates the produce quality (such as color, firmness and size) to the degradation rate which is entirely dependent on the temperature exposition. The product moment correlation coefficient is based on the covariance of the two temperatures and the variances of each individual temperature.It describes how closely air temperature at various points in the load varies with the supply air temperature. These computations are not described due to space constraints.

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