Intelligent Supply Chain Management System

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***Abstract*—Internet of Things aims at integrating networked information systems to real world entities. It connects objects such as smart phones, sensors, Light Emitting Diodes (LED) displays, vehicles through the internet allowing them to interact and exchange information among themselves. In today's times IoT has found its application in practically every walk of life and supply chain management is no exception. At present, supply chains are becoming increasingly complex, where suppliers and customers stretch between various countries and continents. The biggest problem faced by manufacturers is to optimize supply chain performance and reduce operational costs over such large geographical stretches. IoT acts as a solution to this problem as it facilitates the use of Wireless Sensor Networks (WSN) in order to interconnect all the various actors in a supply chain. This humongous network of interconnected devices generate massive amounts of data which is difficult to store and process. Cloud computing here plays a role of a facilitator and provides great help in addressing challenges related to storage and processing capabilities. In this paper, we present an Intelligent Supply Chain Management System (ISCMS) that benefits from the amalgamation of IoT and Cloud and provides real time monitoring, tracking and managing of goods from the perspective of a supplier, customer and shipper. We also propose an algorithm that depicts the working of our system. The proposed Intelligent Supply Chain Management System along with the algorithm are simulated using the iFogSim simulator. To this end, we illustrate the working of our proposed system along with the simulated results.**

Keywords—Internet of Things; Cloud Computing; supply chain management system; iFogSim

I. Introduction

The recent advancements in the field of wireless sensing technology has given rise to the surfacing of a wide range of applications ranging from various domains such as healthcare, infrastructure, power sector, social networking, etc. Among such domains, supply chain management is regarded as one of the most apt domains wherein wireless sensing technology along with other new age technologies (Cloud computing) can be used to enhance the profitability and the efficiency of the domain. However, since the past couple of decades many supply chain management systems have been proposed but they lacked features such as real time monitoring, traceability, data analytics and secure customer authentication. Thanks to the recent innovations that have taken place in the field of Internet of Things (IoT) and Cloud Computing which have indeed provided solutions to these problems. The concept of Internet of Things talks about an information sharing ecosystem wherein heterogeneous devices (things) are interconnected through wired or wireless networks. IoT can be considered as an advancement of machine to machine (M2M) communication which involves integration of sensors, actuators and other embedded devices in form of an IP based networking model [1]. IoT facilitates the use of Wireless Sensor Networks (WSN) in order to collect information from various sensors, which is then exchanged and depicted onto the real world through the help of actuators. IoT is not just about embedded devices connected to one another, rather, it consists of a large set of actors such as sensors, things, sensor networks, actuators and humans that lead to its proper functioning [2]. It is indeed the concept of IoT that provides real time tracking, monitoring and management of goods and items in a supply chain management system. Talking of Cloud computing, it is the next big paradigm shift that has taken place in the IT industry.

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Cloud provides features such as on demand scalability, flexibility, dynamic resource allocation and above all the pay as you use model [3]. These all benefits of cloud provide great opportunities to both service providers and end users in form of unlimited storage and processing capabilities. Cloud allows service providers to host there services which can be accessed from any geographical location through internet connected devices. A combination of both these technologies when used in creating a supply chain management system provides not only quantitative benefits in form of business optimizationbut also quantitative benefits such as customer satisfaction. This paper aims at providing an Intelligent Supply Chain Management System (ISCMS) that combines the benefits of Internet of Things and Cloud in order to deliver the right product to the right destination at the correct time.

The rest of the paper is categorized as follows: Section II elucidates the proposed work wherein the proposed system and its working are explained. Section III discusses the algorithm that depicts the workflow of the entire system, whereas its successful simulation and its results are discussed in Section IV. Finally, Section V concludes the paper.

II. Proposed Work

In the past, many supply chain management systems have been proposed but most of them had their focus on the source and destination rather than on the journey. In this section, we present an Intelligent Supply Chain Management System (ISCMS) that is based on the amalgamation of Internet of Things and Cloud computing and provides efficient transportation of the right product in the right quantity to the right destination at the right time [4]. The system would provide real time monitoring, management and end to end traceability of the entire supply chain. The aim of this system would be to create an interactive supply chain ecosystem wherein your product, the container in which it is being carried and the vehicle responsible for its transportation will be telling you where they are, in what conditions are they being transported, what routes have been taken for their transportation and their current location. All in all this intelligent system would ensure efficiency of the supply chain, quality control, cost benefits and customersatisfaction.

[21] *Parameter to Identify*

Fig. 18. The heart and soul of the Intelligent Supply Chain Management System are the sensors that would be sensing information related to each and every product on a real time basis. But before the use of sensors we need to specify the parameters which the sensors need to sense [5].

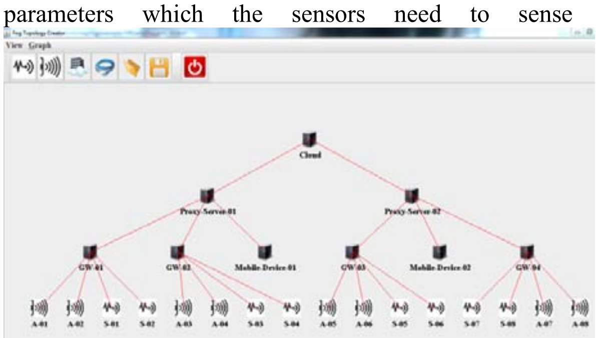

Fig. 1. Physical Topology

Below are the list of parameters that would be sensed in the ISCMS.

- Container Identification (Container ID, Container type, Container specifications)
- Transportation Conditions (Vehicle speed, movement of the vehicle)
- Routes (Items having same destination can be loaded into a single vehicle)
- Environmental Conditions (temperature, pressure, humidity, Moisture)
- Location
- Product Information (Product type, Product name, Product ID, date of manufacturing, Expiry date of the product)
- Customer Identification (Customer ID, Customer name, Customer contact details, Customer authentication details)
- Product Surrounding Conditions (PH, type of other nearby products)
- Source and Destination Information
- Time
- Quantity of a Product (Weight, Number of items)
- Packaging Status

[22] *Infrrustruture Layer*

In this subsection, we would be talking about the infrastructure layer of our Intelligent Supply Chain Management System. The infrastructure layer comprises of all the physical entities that constitute the entire system. Here we would be discussing about all the seven actors (physical entities), their roles, basic functionalities and the way in which they communicate among themselves. The infrastructure layer of the system can also be addressed as the physical topology of the system wherein all physical entities exchange information and represent acomplete workflow. The following figure illustrates the physical topology of the ISCMS which has been created using the iFogSim toolkit.

- *Sensors*: Sensors are the eyes and ears of the system as they detect occurrence of events, surrounding conditions and transmit the collected information. The work of the sensors is to monitor and perceive events or phenomena that take place in the physical world. Every sensor can be categorized on the basis of three parameters namely, sensor type, methodology and sensing parameters. Sensor type defines which type of sensor it is i.e. whether it is a homogeneous or a heterogeneous senor or it is a single dimensional or a multidimensional sensor. Methodology talks about the ways in which a sensor gathers information. It can be either active or passive in nature. Sensing parameters are the number of parameters which a sensor can sense. A sensor might just sense one parameter like body temperature or many parameters like in the case of an ECG. Below are some of the sensors which we have used during creation of the system.

i. Temperature Sensor
ii. Humidity Sensor
iii. PH Sensor
iv. Chemical Sensor
v. Tilt Sensor
vi. Location Sensor
vii. RFID Tag
viii. Vehicle Speed Sensor (VSS)
ix. Pressure Sensor
x. Real Time Clock (RTC)
xi. Moisture Sensor

- *Gateway*: All the information that has been sensed and collected by the sensors is transmitted to the gateways. Gateways act as a common point of contact wherein diverse kinds of information coming from heterogeneous types of sensors gets collected. It is the gateway which is responsible for the global addressing of Sensor Nodes (SN) by making use of IPv4 addresses [6]. Each gateway is allotted a coverage area, wherein each sensor node has been given an IP address thus facilitating efficient identification of objects within that area. Every gateway is allocated more than one area so as to enhance the granularity of SN identification. The gateway also keeps track of its neighboring gateways along with the total number of SNs functioning in its area. Finally the gateway transmits all forms of unstructured information to its subsequent proxy servers. Entities named as "GW" represent Gateways in the physical topology.
- *Proxy Server*: It acts as an intermediary node for requests coming from a supplier or a customer. The purpose of adding a proxy server is to enhance the response time of the system as communicating directly with the cloud server could lead to increased latency cost. Proxy server provides a communication link between Cloud and the rest of the system and also offers local processing and storage capabilities in order to boost the efficiency of the system. Any request coming from a mobile device is addressed by the proxy server which then subsequently informs the Cloud and other devices on the network. All the instruction given by the Cloud are communicated through the proxy server to the respective devices. The proxy server can also be considered as a Fog computing[7] element as it resides at the edge of the network making its access both easy and efficient. It is the proxy server which on regular intervals updates the Cloud about information regarding every entity involved in the system.

- *Mobile Device*: It acts as a representative for a supplier of or a customer. It is the mobile device which allows the end user to monitor, track and manage the entire supply chain on a real time basis. Any alert that is triggered from a sensor node is directly communicated to the mobile device in wait of an appropriate response.

- *Sensor Node (SN):* It is the transportation vehicle that carries various kinds of goods. It can also be seen as a collection of multiple sensors which have been installed on a particular vehicle. Each sensor node is provided an IP address which helps in its unique identification. Every sensor node communicates all of its sensor data to its subsequent gateway. Entities starting with the letter "S" represent the Sensor Node in the physical topology.

- *Actuator (Display):* Every transportation vehicle has an LED display installed that informs the pilot about the state and condition of goods which the vehicle is carrying. The actuator also displays any type of an alert raised by a sensor along with the response to that alert. Entities starting with the letter "A" represent the Actuator in the physical topology.

[23] *Application Layer*

In this subsection, we would be discussing the application layer of our Intelligent Supply Chain Management System. This layer comprises of four different application modules which constitute the working and the information flow of the entire system. We also specify the kind of information which each of these modules process and communicate. These fourapplication modules have also been mentioned in the Section IV.

- *Controller*: The purpose of the controller is to manage and govern the entire system. It is the controller which orchestrates the functionalities of other application modules and entities within the system. The controller resides at the Cloud end and has detailed information regarding every product, customer, supplier, source, destination, sensor node, actuator, gateway and proxy server. All of this information is stored and processed by the controller in order to generate optimized product preferences and logical distribution patterns. The controller establishes a one to one connection with the middleware and circulates all of its orders through it. It is the controller which generates detailed product supply chain reports on the basis of supply chain performance, quality control and alters triggered by the sensors.

- *Middleware*: The purpose of the middleware is to receive orders from the controller and communicate them to the respective entities involved in the system. The middleware resides at the proxy server and regularly updates the controller regarding the status and working of all other entities. The middleware processes incoming information from sensor nodes along with the requests coming from the mobile application. It then communicates this information to the controller in response of a suitable order.

- *Mobile application*: It resides on the mobile device of a supplier or a customer and allows them to interact, monitor and manage the rest of the entities of the system. The mobile application receives alert notifications from the middleware and responds to them in form of suitable actions which are then conveyed to the pilot through the user interface. It is the mobile application which allows the end users to have real time access to the supply chain from any part of the world.

- *User Interface*: It resides on the vehicle that is responsible for the transportation of goods. It informs the pilot of the vehicle about the route to be taken, sensor node status, supplier information, sensor alert notifications and end user requests. There is a one to one communication between the user interface and the middleware.

III. Algorithm

The working of the ISCMS could be explained through the illustration of the algorithm that forms the core for it. The algorithm depicts the functioning of the system by representing the relationship between various actors andthe information that they share in form of parameters among themselves.

SYMBOL TABLE

Symbol	**Meaning**
γt	Alert, t denotes a specific type of sensor
γa	Alert Action
Φ	Cloud
ά i	Mobile Application, i denotes a specific mobile application
Ψi	Display, i denotes a specific display
δ	Time
θi	Sensor Data, i denotes a specific sensor
αt	Source (Supplier's End), t denotes a specific product
βt	Destination (Customer's End), t denotes a specific product
SNi	Sensor Node (The vehicle that carries various products)
PSi	Proxy Server, i denotes a specific proxy server
GWi	Gateway, i denotes a specific gatewat
St	Sensor, t denotes a specific type of sensor
Ri	Route, i denotes a specific route
Li	Location, i denotes a specific sensor

Function	Functionality
Start()	It marks the start of the entire system
Controller()	It orchestrates the flow of information and controls the working of the entire system.
Middleware()	It manages information at the Proxy Server level
Product_Info()	It is used to keep track of all the information regarding a particular product such as Product Code, Product Price, Product Name, Price, Expiry date of the Product, etc.
Alert_Action()	The purpose of this function is to receive commands from the end user and communicate them to the sensor node in case an alert has been triggered.
Customer_Authentication()	This function keeps track of all the information regarding a customer such as, Customer ID, Customer Name, Customer Firm Name, Customer contact details, Login credentials and thus helps in preventing unauthorized access of goods.
Distribution_Pattern()	It deals with information related to distribution of goods with respect to their transportation routes and area of destination.
Stop()	It marks the end of successful working of the entire system

FUNCTION TABLE

Step 1: Start()

Step 2: Controller()

Step 3: Middleware()

Initialization Block

Step 4: Product_Info()

Step 5: (αt, βt) → Controller()

Step 6: Controller() → Middleware()

Step 7: SNi (θi) → GWi

Step 8: GWi (δ, θi, Li, Ri) → PSi

Step 9: PSi (αt, βt, δ, θi, Li, Ri) → {Ψi, άi, Φ}

Step 10: SNi (St, γt) → GWi

Step 11: GWi (St, γt, Li) → PSi

Step 12: PSi (St, γt, Li, δ, Ri) → { Ψi, άi, Φ} Alert Raised

Step 13: άi → Alert_Action()

Step 14: Alert_Action(γa) → PSi

Step 15: PSi (γa, St, Li, δ, Ri) → { Ψi, Φ}

Step 16: SNi (θi) → Customer_Authentication ()

Step 17: Customer_Authentication () → PSi

Step 18: PSi → { Ψi, άi, Φ}

Step 19: Distribution_Pattern() → Φ

Step 20: Stop()

Step 21: End

Step 1 to Step 4 constitute the initialization block. The functions that are called in them are the first ones to be executed once the system gets started. Step 5 to Step 9 depict the information flow that takes place between various actors of the system. Step 10 to Step 15 are performed in case an alert is triggered by a sensor in response to an unwanted situation. Step 16 to Step 18 illustrates the condition of customer authentication which takes place once the good have reached their desired destination. In Step 19 information related to distribution of goods with respect to their transportation routes and area of destination are processed and analyzed at the cloud end in order to design customized and efficient product lines.

IV. Simulation & Results

The above mentioned algorithm is implemented on iFogSim framework. In iFogSim[8] there are various predefined classes that provide a simulation environment for Internet of Things combined with the benefits of cloud computing. It enables the simulation of resource management and application scheduling policies across edge and cloud resources under different scenarios and conditions.iFogSim is a java based simulation toolkit and can be implemented either using Eclipse or NetBeans IDE. In our case we would be using the eclipse IDE. To run iFogSim on eclipse, we first need to download the eclipse IDE and install it. After successful installation of eclipse IDE, download the latest iFogSim package, extract it and import it in eclipse. Talking of our proposed work we have created our own classes in iFogSim and have portrayed our algorithm in form of java code. The following are the screenshots that depict the working of our algorithm on iFogSim framework.

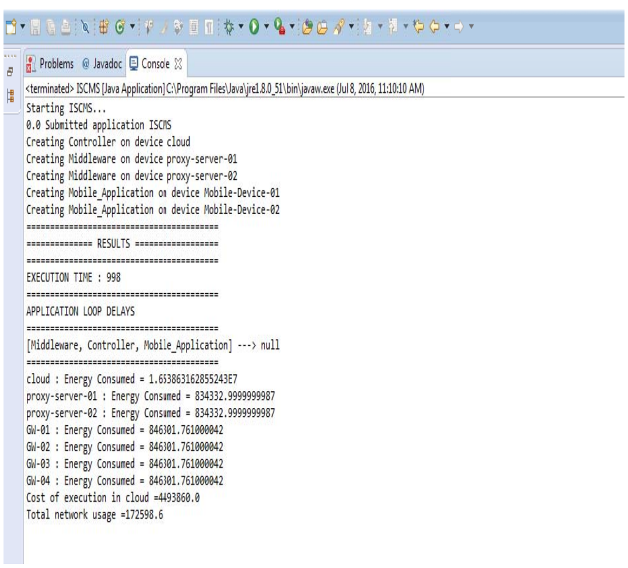

Fig. 2. ISCMS Simulation

The above screenshot depicts the working of the Intelligent Supply Chain Management System. It shows how various application modules are created and allowed to run on different physical infrastructures. First of all the physical entities have been created programmatically and then allowed to run and communicate among themselves. There are in total four physical entities that have been created which have been listed in table x along with their respective configurations. Some pre-defined functions such as createFogDevice(), Sensor(), Actuator() and addAppEdge() from iFogSim have been used extensively throughout this experiment for creating physical entities and establishing connections between them. Certain user defined functions namely, add_Mobile_Device() and add_Gateway() have been used for creating mobile devices and gateways respectively. There are four application modules (controller, middleware, mobile_application, user_interface) that have been created for transfer and processing of information. There are certain data dependencies between these modules, which are modeled using the AppEdge class in iFogSim.

EntityTable

Physical Entity	**Processing Capability (MIPS)**	**RAM (MB)**	**Uplink Bandwidth**	**Downlink Bandwidth**	**Level**
Cloud	44000	40000	100	10000	0
Proxy Server	2000	4000	10000	10000	1
Gateway	500	1000	10000	10000	2
Mobile Device	200	1000	10000	250	3

In order to make our experiment more real we had specified the end-to-end latency of every device loop. Following is the table that lists network latencies between various devices.

Latency Table

Source	**Destination**	**Latency (milliseconds)**
Mobile	Proxy Server	4
Gateway	Proxy Server	4
Proxy Server	Cloud	100

Sensor	Gateway	6
Proxy Server	Mobile	4
Actuator	Gateway	6

During the simulation of our proposed system various metrics reported by iFogSim were collected. The results

of the simulation are demonstrated using three different parameters namely, execution time, energy consumed (Mega Joules) by different category of devices and total network usage (KiloBytes).

V. Conclusion

Supply chain management is one of the many domains where IoT finds its application. We present an Intelligent Supply Chain Management System which is a significant step towards creating an well optimized supply chain. The proposed system is based on the amalgamation of Internet of Things and Cloud computing and provides a real time view of the entire logistics process. We have discussed in this paper, the physical topology as well as the application model for our Intelligent Supply Chain Management System.

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