Research of IOTs Complex Event for Supply Chain Application

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Abstract

In order to solve the logic fault of Internet of things technology applied in the supply chain system, this paper presents processing framework which is based on the context of complex event processing technology. At first, paper analysis the hierarchy of processing framework oriented supply chain applications, and then put forward the situation model of event flow based on complex event, including the establishment of the model, the definition of the event as well as the event description language. The context-aware framework based on complex event processing technology can solve the problem that the underlying data cannot be used efficiently bythe upper, which is proved bya typical case existingin the supply chain. As a result, it can improve the reaction speed of the supply chain system, reduce supply chain inventory as well as bullwhip effect.

Keywords**：** *supply chain, internet of things, complex event processing, context-aware framework*

1. Introduction

With the application of the Internet of Things technology in the supply chain, it can break through the "bottleneck" problems underlying data acquisition in the field of logistics. As supply chain is a complex system, it becomes a major challenge currently that how to efficiently use the Internet of Things data in the supply chain. Complex event processing technology is a new technology for information processing. Through user defining the business information that is self-interested, it can define the underlying data as an event, then filter and aggregation processing the underlying data. At the same time, multiple events will become a complex event with more complex business information based on the business. Through the creation of complex event-based context-aware systems, it can effectively solve the problem of faults between the underlying Internet of Things data and the upper business. Based on existing researches, this paper presents a supply chain-oriented context processing framework based on the events which is for the IntelliSense supply chain system. It can solve the problem existingin the application of Internet of Things, and provide a support for the upper decision-making.

2. Existing Researches

In the management of the supply chain, the things that companies really need are the business logic contained behind the raw data which can support decisions. Therefore, how to efficiently deal with and apply the underlying data of supply chain system becomes the main problem facing supply chain system based on Internet of Things technology.

Complex event processing (CEP) technology proposed by D. Luckham, Stanford University, is a new event handler method evolved by the active database research. Active data processing is based on traditional relational database, and stores data as a triggering event in a specific way, then generates an event associated with the trigger event. In the 1980s, the emergence of SQL has solved the problem of querying data in a structured way. 1990s, Sybase first proposed concept of triggers, closely linked the event handling to data layer, and it can trigger downstream actions along with some features of the data. But the flip-flop technique has strong interference, the ability to handle the amount and complexity of data is limited, and there is no concept of time series. About 2000, manufacturers began to do processing mechanism

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based on event and data-stream in this direction. And now has gradually formed a special branch in software industry – CEP, namely complex event processing [1]

Complex event processing processes the data as theevent stream. Therefore, the complex event processing can complete processing operation within the data stream, instead the information in the memory. Also it can filter the vast amounts of real-time data, which improvesthe processing efficiency. For a complex event processing system, we need to design the properties, the structure, the model and processing language of the event. Existing researches for complex event focus on RFID, and complex event detection methods focus on event-centric processing mode. The detection algorithm of complex event mainly includes finite automata-based model, Petri nets-based model, matched tree-based model and directed graph-based model [2, 3]. Description for complex event processing language is not a lot, and the relative mature is the SASE language and some extensions based on the SASE language [4].

Situational processing framework is the core of context-aware system. The research of the system framework is quite rich, and it already has a large number of context-aware system framework now, such as Gaia, ACAI, Multi-Agent, CAPpella, ActiveCampus, CAPNET, SOCAM, CASM, DESM, CASA, and so on. [5] proposed the Gaia system framework, which is a context-aware computing framework that is similar to the traditional operating system. This framework makes the intelligent space and resources abstracted as programmable entities so that it is easy for developers to build applications. The ActiveCampus framework proposed by [6, 7] was a typical client-server architecture-based framework. The significant character of the framework is supporting the high integration between the division of responsibility among the components and services; CARISMA framework building in [8] allows monitoring the internal behavior of the framework and modifying when needed with the reflection model; [9] proposed anevent-driven bus structure and a context-aware model framework with rule-based event filtering mechanism.The framework includes sensor layer, the event bus and the application service layer. At the same time, it invokes the interactionbetween the application service and userin an event-triggered way. It establishes the rule-based event filtering mechanisms, which can shield theinvalid events.

The above framework systems are all based on the specific user scenarios. Although their focuses and scopes of application are different, they are oftenconsisted of context-aware, situational conversion trigger execution and some other parts. Until now, the research about system for various types of users and complex event-based context-aware framework is not enough rich.

3. Context-aware Framework based on Complex Event

In this paper, the entire context-aware framework structure is divided into five layers based on the different users of each link in the supply chain system device-aware layer, enterprisecomplex event processing layer, supply chain complex event processing layer, information sharing service layerand the application of the decision-making layerin the bottom-up order. As shown in the Figure 1, the lowest level is device-aware layer, which is responsible for controlling variousmodels of reader distributed in different places; upward event is processing layer which is responsible for handling the events and data from original equipment perception layer; then upward is information sharing service layer, which transfers and releases business event information from the event processing layer to the upper application system through the pull service and push service. The top layer is the application of the decision-making layer. According to the business logic defined semantics rules, the managers in the various links of the supply chain can invoke event information based on semantic rules through information sharing service layer. The framework of the overall structure is shown in Figure 1.

3.1. Device-aware Layer

Device-aware layer is one of the functional modules in the situational perceptual framework, which is mainly responsible for the perception of environmental information in the supply chain system. The devices in the Context-aware framework of supply chain include RFID reader (mobile and fixed), wireless sensor network devices, positioning terminal devices, smart mobile devices and other hardware systems.Device-aware layer is the basis of the entire distribution context-aware framework, which is used to shield the differences among the different manufacturers, and various models of hardware, as well as to provide accurate, real-time raw data to the event processing layer.

3.2. Enterprise Complex Event Processing Layer

Given each node in the supply chain system existing the large-scale original acquisition data, decentralized data, redundant information and less semantic information, the complex event processing layer provides the appropriate scale of the semantics complex events to the supply chain complex event processing layer through caching, filtering, polymerizing and semantically analyzing the original data. Corporate complex event processing layer includes three parts: original event cache, the original event filtering engine, complex event processing services.

3.3. Supply Chain Complex Event Processing Layer

According to the business existing among different enterprises in supply chain system (such as ordering, distribution, product traceability and some other integrated business), supply chain complex event processing layer generatessupply chain process-oriented complex events based on the complex events generated by enterprise complex event processing layer.

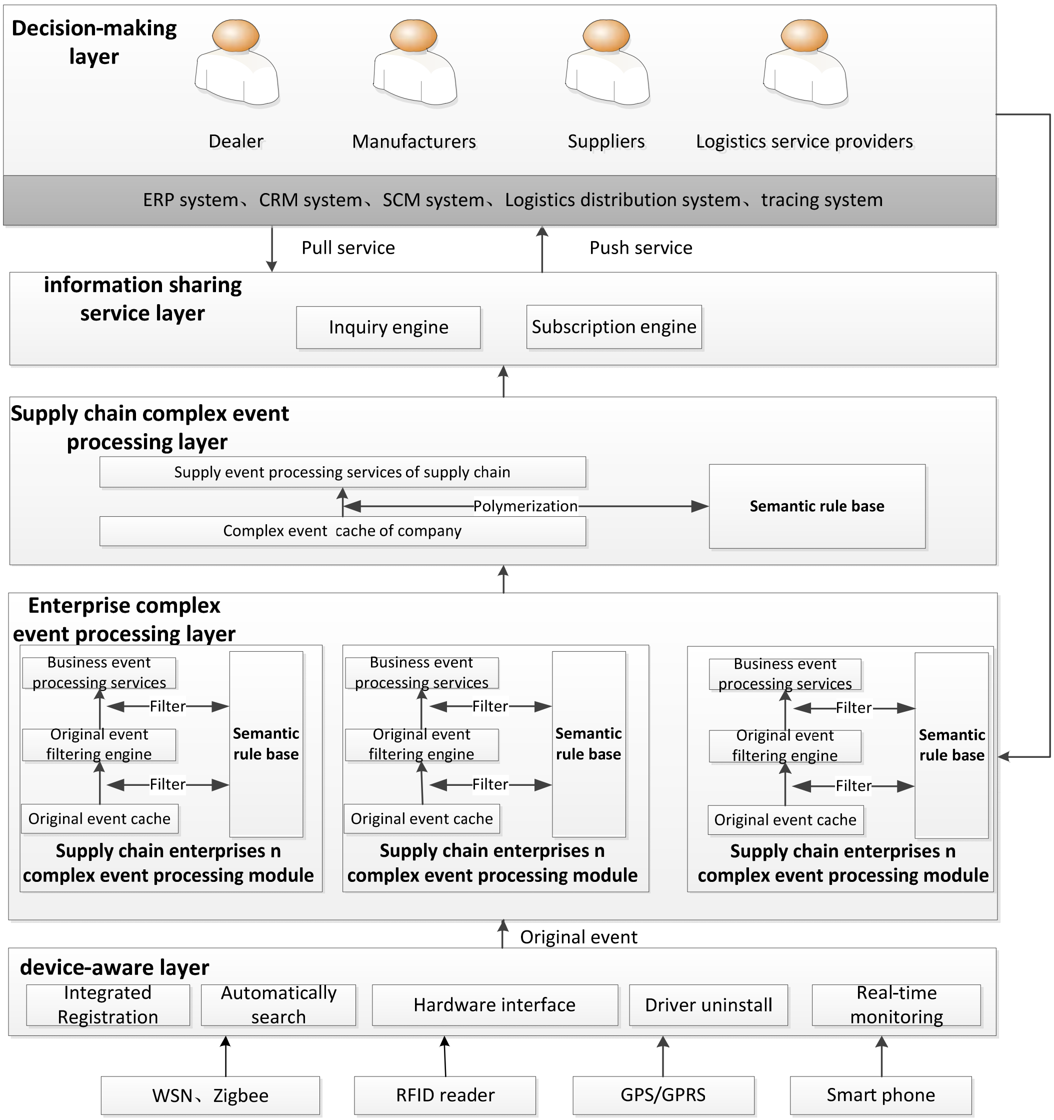
Decision-making layer
Dealer
Manufacturers
Suppliers
Logistics service providers
ERP system、CRM system、SCM system、Logistics distribution system、tracing system
Pull service
Push service
information sharing service layer
Inquiry engine
Subscription engine
Supply chain complex event processing layer
Supply event processing services of supply chain
Polymerization
Semantic rule base
Complex event cache of company
Enterprise complex event processing layer
Business event processing services
Filter
Original event filtering engine
Semantic rule base
Filter
Original event cache
Supply chain enterprises n complex event processing module
Business event processing services
Filter
Original event filtering engine
Semantic rule base
Filter
Original event cache
Supply chain enterprises n complex event processing module
Business event processing services
Filter
Original event filtering engine
Semantic rule base
Filter
Original event cache
Supply chain enterprises n complex event processing module
Original event
device-aware layer
Integrated Registration
Automatically search
Hardware interface
Driver uninstall
Real-time monitoring
WSN、Zigbee
RFID reader
GPS/GPRS
Smart phone

Figure 1. Context-aware Framework based on Complex Event

3.4. Information Sharing Service Layer

Information sharing service layer provides a unified interface for different applications in the supply chain system, the usersin the system can invoke service by publish/subscribe model. Publish/subscribe model is a loosely coupled communication paradigm which is oriented distributed computing environment. In pub/sub system, because of the associated theme, the publishers and subscribers do not have to know where the other or online at the same time. It realizes the multidimensional coupling on time, space and data communications between both sides.

Information publishers send the information to the event agent in the form of "events"; Information subscribers issue a subscription to the event broker to show their interests for specific kinds of events in the system; As event brokers, they should ensure the event being sentto all its subscribers timely and reliably. Pub/sub system enables information producers and consumers are fully coupled at the three aspects of time, space, and control flow, and thus well positioned to meet the needs of large-scale, highly dynamic distributed systems.

4. Context Model of Rule-based Initiative Event Stream

4.1. Intelligent Supply Chain System Modeling

In the supply chain system based on Internet of Things technology that includes supply enterprises, production companies, distribution companies, retail enterprises, the data acquisition devicesinclude RFID, GPS, Zigbee and so on. Therefore,events in the framework mainly include RFID event, GPS event, Zigbee event. At various aspects of the system, we use a real-time and active acquisition data stream, which can generate standard eventwith real-time data from the sensing equipment deployed in the different logistics chain. Complex event processing in the system is divided into three levels: the event filtering server, the local proxy server, and supply chain shared server.

At first, the context information capturedby the aware devices need to be pre-processed and filtered by the event filtering server, then it will generate a standard format of the original event which will be uploaded to the local proxy server later. Complex event processing module in the local proxy server make a pretreatment for the event according to the semantic rules, masked invalid or redundant events. And at the same time release the illegal operation and business events that the users interested in to the event subscribers. After sharing and aggregating, the complex eventsof local proxy server generate the complex events in the level of the supply chain.

In the system, every aware device has a unique identification label, and is registered the aware device service information in the business database, including the aware device ID, device type, affiliated enterprises, business links and some other information.By querying the sensing equipment, you can get theregistration information which is used to determine the type of the operating businesses, the enterprise and other related information that the data tuples represent. It can also realize the associated query among the enterprise business data with the variable.

4.2. Events Defined

According to the characteristics of the events happened in the supply chain system under the condition of IOTs, the events are divided into practical and virtual events. Real events refer to the events that the hardware equipment reads data spontaneously, such as RFID read event, GPS data transmission event, ZigBee data transfer event. Virtual events refer to the events non-spontaneously, such as business related documents, such as, production plan, production orders, outbound order, warehouse, etc.Divided according to the different levels of the event, the event is divided into atomic events, basic complex events and supply chain complex events.

Event Type: abstract description for common attribute information of metadata belonging to the same class of event (instance), *E = (Etype, Space, Time, Info)*.

Event type descripts the description information and property type which is related to the event when an event occurs. Etype is event category which is used to uniquely identify the type of event. Space represents the spatial coordinates of the events, such as the reader ID ofRFID read events, can also be expressed reader collection; Time represents the incident time coordinates or time range; Info represents content informationof the event,*info= {< info 1，value*

1>，< info 2， value 2>， …， < info n，value n> }， n ≥0， also can be defined as the range of variables. A name value corresponds to a tuple, it specified the variables included in the different types of events, which is similar to the simple object instance member function. It has variable name, variable values, and event instance belonging to some sort of event type. Thelimited relationship between the variables is defined in the type of event, and the event instance itself does not describe the relationship between the properties. Content of events RFID read: *info = {<tag FFFF00000000000000000001>}*; temperature and humidity content of the event sent by the ZigBee: *info = {<the temp 30>, <humi, 30>}*. This article will use XML to define atomic events type of complex event, such as RFID reading the event types of specified label collection can be defined as follows:

```
<Event  Eid =EVENT>
<HardwareID> SRIN001</HardwareID>
<TIme>
<STime>201208220909</STime>
<ETime>201208220909</ETime>
</TIme>
<Iinfo>
<tag>
<stag>FFFF00000000000000000001</stag>
<etag>FFFF00000000000000999999</etag>
</tag>
</Iinfo>
</Event>
```

Event instance:individual event of an event type occurs, can be expressed as *EVENT e=(space, time, info)*, EVENT represents the type of event, e represents the event instance. Following take the original event to RFID: RFID reader once capture the action of the label as an example:

EVENT e <"01004001", "201208201541", "FFFF00000000000000000001"> can be described as 00000001 reader read a library event marked with FFFF00000000000000000001 at the time point 201,208,201,541. The system can also be judged on a property of the event, such as e.ID = "01,004,001" eI = "00000000000000000000001".

(1) Atomic events

As the basic unit of event detection, semantic information of each the atomic event is limited.Through caching and processing of the original event, and the polymerization of a large number of atomic the event, you can produce complex event contains business information.

(2) Basic Complex Event

The basic complex event is the behavior with certain basic business semanticson the basis of atomic events flow, according to the single internal business logic abstraction. Such as warehouse management, a library, storageof the goods can be considered as a basic complex event. The basic complex event is defined by the upper application system through semantic rule base according to target business. Through subscribing an atomic event or more atoms event stream,the detection of basic complex event solves the fault between the underlying data and the upper application, so that it can improve the efficiency of the system processing.

(3) The ComplexEvent of the Supply Chain

The complex events of the supply chain is a composite event oriented different enterprisesof supply chain systembased on the basic complex events. The complex events of the supply chain are the business logic relationship abstracted among the enterprises of the supply chain, which is based on basic complex events, combined with virtual events in the supply chain system. Such as retail enterprises in the supply chain system, when the export reader of the warehouse read the event about the product out of the library, while querying orders, it can make reasonably accurate judgments on the stock according toinventory and ordering.

4.3. Description Language of Complex Event

SASE Event Language is an open and relatively mature complex event description language based on event stream. On the basis of the SAS language, this paper presents a complex event description language which is oriented supply chain system based on Internet of Things. Its formulation is closed to the mathematical expression, which can make accurate definition and description of the atomic event stream and complex event. Also it can match event type, event information,eventtime and event space of the event stream, so as to define a variety of complex events. Its grammatical structure is as follows:

EVENT <event expression exp>
The WHERE <conditional expression q>
[AT WITHIN BETWEEN] <time expression t>
TODO <action expression a>

Its semantics: when event expression exp occurring in the specified timeframes of time expression *t*, meeting the constraints described in the conditions expression *q*, then it may trigger the contents described in action expression *a*.

(1) Definition of Event Expressions

Event Expression: business-related events occurred in the system described by event type and operator. *(A a)* is the simplest event expression. Event expression is an important part of the complex event description language, reflecting the logic match of business. Event type is referred to a class of events, in capital letters, such as *A*; The event instance is a specific event, in lowercase letters, such as *a*. An event type is similar to a class, while an event instance is an object instantiated by event type. And an event object can have only one event type.

(2) Operator

AND (logical *AND*): Indicates when two events connected by*AND*occur, which is synonymous of the logic *AND*. The formal definition is as follows: *Event1 <id1,t1,l1,m1> AND Event 2 <id2, t2, l2, m2>* said that the two events occurred.

OR (logical *OR*): At least one of two events connected by*OR*occurs, which is synonymous of the logic *OR*. The formal definition is as follows: Event1 *OR* Event2 indicates that at least one of the event types occurs.

NOT (negation): the event does not occur, which is synonymous of the logic*NO*. Events modified by*NOT*are negative events. The formal definition is as follows: *NOT (Event1)* indicates that the event does not occur.

SQL (continuous): events occur according to a certain time sequence, such as: *SQL ((A a), (B b), (C c))*indicates between event instance a, c, event instance b occurs.

REP (event recurring): one incident recurring, such as *REP (en)*, said the event e occurs n times.

Operator precedence: in descending order of the *REP, NOT, AND, OR, SQL*. Meanwhile, the operator has the following properties:

If *Event1*is event expression, *NOT (Event1)* is alsoan event expressions.

If *Event1, Event2*are both events expressions, *(Event1AND Event2)*is also an event expression

If *Event1, Event2* are event expressions,*(Event1 OR Event2)* is also an event expression.

(3) Conditions expression

Conditional expression makes restrictions on the conditions of event occurrence. Conditional expression can use the properties and constants of event instance to make a compare, which is called the constant test. Attributes of event instance in the event expression as variables can also be compared with each other, which is called variable parameter test; and the two testsboth occur, it is called hybrid test. The following three conditional expressions are examples of constant test, variable parameter test and mixed test.

WHERE a.id=”021903” OR a.type_id=”039”
WHERE a.id=b.id AND c.weight < d.weight
WHERE a.vendor=”021903” AND a.id=b.id

In *WHERE* expressions, (*AND*) symbol indicates relationship of “and”,and (*OR*) symbol indicates relationship of “or”.

(4) Time Expression

WITHIN: several events occur within a continuous time. Event1 *AND Event2 WITHIN 1hours* indicates Event1 and Event2 occurred within one hour continuous.

AT: event occurred at the time point. Event1 *AT 15:06* said that the incident occurred at 15:06, and is equal to Event1.t = 15:06.

BETWEEN: events occur in a certain period of time. Event1 *BETWEEN (15:06, 15:07)* indicates Event1 occurred between 15:06 and 15:07.

(5) Action Expression

In the processing of original event stream, when the event expressions, conditional expressions, time expressions are all satisfied, action expression will be triggered, such as alarming, taking automatically measures of the system.

While running, the sensing equipment of device sensing layer acquires in realtime environment and raw data related tousersafter receiving the task. Then make some pretreatments, encapsulated as a standard event expression of the framework. For example, a transport vehicle starts to send the information of location and speed to the server after receiving waybill. According to business needs, users of different links in the supply chain system define the semantic rules, format scenario instance, and store in the base of the semantic rules. If the event processing layer found matching scene, it would trigger the specified event. Computing entities in the framework communicate in a loosely coupled way, division with each other but also cooperate with each other. The loose coupling mechanism makes the system easy to extend and maintain. For example, in smart supply chain delivery system which is based on Internet of Things, the warehouse management system consisted of smart storage management system, smart shelves, and smart environmental monitoring system based on RFID, can achieve the intelligent management of the warehouse.In the daily running of the system, the underlying IOTs equipment will produce a large number of original events, such as RFID read events, ZibBee read events; basic events such as warehousing events, the library events, temperature events, humidity events.

The following are examples of the daily business of the logistics system described by the custom semantic rules language.

```
Example 1: EVENT (SR sr) AND (OT ot)
           WHERE sr.space = '000021 'AND ot.temp> 35
           WITHIN 1 minute
           TODO alert
```

It indicatesthe temperature of shelf equipped with readerNO. 000021 is over 35 degrees. Example 1 shows that if the temperature of shelf equipped with reader No. 000021is too high in a short time, it will trigger an alarm event.

```
Example 2: EVENT SQL (ENR enr (NOT (CR cr2)), EXR exr)
            WHERE enr.id = cr2.id AND exr.id = cr2.id
             WITHIN 12hours
             TODO report
```

In Example 2, *ENR* represents the storage event generated by card reader at the entrance of warehouse, *EXR* represents reader scan event at the export, and*CR* shows outbound events. The *enr, cr2, EXR* are three event instances. The significance of the described is to monitor products that meet the following criteria: Complete warehousing operation within 12 hours, and go through the warehouse export without through the normal scanning operation of the exit reader. If the detected results indicate the products are illegally out of the library, it will send a report to the administrator.

The definition of the basic complex events is illustrated by the above. It can provide intelligent management support to the daily management business among enterprises in the supply chain system with the basic definition of complex events, such as reducing manual errors, real-time monitoring for abnormal situation has occurred. If find problems in the daily operations, you can improve the intellectualization and automation of supply chain management system in the way of improving the semantic rule base by defining semantic rules to gradually, further reducing the error message, redundant information, and illegal business operations.

5. Application Examples

The supply chain system with supermarket as the sales side is usually consisted of supermarkets, distribution centers, manufacturing enterprises. Enterprise in the supply chain has a corresponding safety stock.While in the day-to-day management, inventory is dynamic. As a result, it is difficult to fill the safety stock and timely replenish in the management.

Meanwhile, in the supply chain system, the enterprises of the supply chain manage inventory alone, which results in the inventory information silos. So the system inevitably produces distortions and delay of the demand information, which make it impossibleto predict the needs of users accurately. By taking the supply chain scenario described as follows for example, this section will solve the above problems through the application of complex event technology in the supply chain system based on Internet of Things technology.

Taking a product A in the supply chainfor example, assumethe safety stock of the foreground sales supermarket is 10, distribution enterprise is 50, the producers is 100. At the same time, assume inventory statistics way of the various aspects control according to out of storage(supermarket foreground is sales), so atomic event type of the safety stock event is the outbound event and warehousing event, respectively.

Shelving events and sale events of the supermarket are defined as scenario three.

The shelving event type of productA (SRIN001 indicates the reader ID at the entrance of the supermarket):

```
<Event name=SIN>
<HardwareID> SRIN001</HardwareID>
<TIme>
<STime>201208220909</STime>
<ETime>201208220909</ETime>
</TIme>
<Iinfo>
<tag>
<stag>FFFF000000000000000000001</stag>
<etag>FFFF000000000000000999999</etag>
</tag>
</Iinfo>
</Event>
```

The sale event type of productA (SRSEAl001 indicates the reader ID at the entrance of the supermarket):

```
<Event name=SSALE>
<HardwareID> SSALE001</HardwareID>
<TIme>
<STime>201208220909</STime>
<ETime>201208220909</ETime>
</TIme>
<Iinfo>
<tag>
<stag>FFFF000000000000000000001</stag>
<etag>FFFF000000000000000999999</etag>
</tag>
</Iinfo>
</Event>
```

After the filtering process, atomic events from bottom of the system are tested to comply with the above rules, which indicatethe incident occurs. Such as events:

SIN sin <*SRIN001, 201208220909, ffff00010001000000000001*>indicates the shelving event SiN of product occurred;

The supermarket mayappear wrong operation or theft in the day-to-day operation and management. If complex event *((NOT (SSALE)) AND (SOUT)* occurs, which said the merchandise has not been brought out of the supermarket without sold, indicating the merchandise stolen event, the system will alarm. As supermarket goods are below the safety stock,the system will prompt replenishment. Such as complex event: *(REP (SSALE 90)) AND (REP (SON10)) AND (REP (SIN0))* occurs, indicating supermarket sales 90 products, the remaining 10 products are on the shelves, the number of supermarket shelves commodity is0 in this period of time. Ifbelow safety stock, the system will prompt the supermarket replenishment.

If the safety stock in the supermarket is 10, we can define safety stock events: *(REP (SSALE 90)) AND (REP (SIN0))* said that the number of selling goods is 90 whilethere is no replenishment to the shelves in the supermarket during this period. Then if the 90th A is sold in the supermarket, the safety stock event occurs. The system can be set to make orders automatically.Events described are as follows:

if REP（SSALE90）AND（REP（SIN0））
Within 24hours
Todo SOrders（pruduct A，100，distribution centers A）

In distribution center, the safety stock of product A is set as100, we can define safety stock events in the distribution center as: *(REP (DOUT900)) AND (REP (DIN0))* said that the number of selling merchandise is 90 while there is no storage operation in distribution centers during this period. Then if the readersat the export of distribution center read the outbound number of products A is 900 (the 900thgood is out of the library), the safety stock event occurs. The system can be set to make orders automatically. Events described are as follows:

if REP（DOUT900）AND（REP（DIN0））
Within 24hours
Todo DOrders（pruductA，1000，ManufacturerA）

Throughout the supply chain, if safety stock events occur at the retail end and distribution sectors, such as: *((SSALE90) AND (REP (SIN0))) AND ((SSALE90) AND (the REP (SIN0))) AND ((-REP (DOUT900)) AND ((REP (DIN0))))*, which indicates more than one link in the supply chain appear low inventory phenomenon, so the supply chain manufacturers need to adjust the production plan to ensure sufficient supply in the supply chain.

By the analysis of above cases,the supply chain system based on IOTs applying complex events can greatly improve the transmission and sharing of information, improve inventory accuracy, and reduce response time, so as to effectively alleviate the bullwhip effect.

6. Conclusion

With the development of the Internet of Things technology, Context-aware Services will get more and more applications and attentions in the supply chain system. This paper presents a situational awareness framework which is oriented to supply chain system. The framework is based on complex event processing, and can deal with the uncertain contextual information through the definition of the semantic rules. Through integratingthe supply chain business scenario and the Internet of Things data, it providesa semantics senior situation for the upper application. At the same time, it can solve the problems existing in the process of Internet of things being applied in the supply chain system, and provide a support for the upper`s decision-making.As this paper only proposes a context-aware framework of supply chain-oriented applications, so we need to do further research on the specific content such as complex event processing algorithms, definition for semantic rules and the language for event description.

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