M2M Communications for Smart City: An Event-Based Architecture

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Abstract — **Machine to machine (M2M) communications will lead to dramatic changes in the applications and services offered to citizens, allowing smart city to become a reality. In this article, we first introduce the new tendency in M2M development and analyze the construction frame of application systems in smart city. Then, an event-based architecture depending on SOFIA project is built to allow the management and cooperation among M2M components by mean of event manager. Based on this architecture, we conduct a case study in a vehicular context. M2M network architecture is introduced for vehicular networks. Finally, an event processing flow of vehicle maintenance services is designed to manage the mission-critical wireless messages.**

Keywords – machine to machine communications; smart city; internet of things; wireless sensor networks; vehicular networks; event-based architecture; cloud computing

I. INTRODUCTION

Machine to machine (M2M) refers to the autonomous communications among computers, embedded processors, smart sensors, actuators and mobile devices without or with limited human intervention [1, 2]. The rationale behind M2M communications is based on two observations: 1) a networked machine is more valuable than an isolated one; 2) when multiple machines are interconnected, more autonomous and intelligent applications can be generated. Now, the impacts of M2M communications will continuously increase in this decade according to previous predictions [3]. For example, researchers predict that by 2014, without the requirement of any human interventions, there will be 1.5 billion wirelessly connected devices excluding mobile phones, and thus leading to an unprecedented increase in M2M data. The various applications of M2M have already started to emerge in several fields, such as healthcare, smart robots, smart grids, smart home technologies, intelligent transportation systems and smart cities [4]. Figure 1 shows the potential market for M2M communications [5].

Recent advances in the fields of wireless technology, advanced communications and intelligent systems have exhibited a strong potential and tendency on improving human life in every facet [6, 7]. Smart city, the important strategy of IBM, mainly focuses on applying next-generation information technologies to all walks of life, embedding sensors and actuators to hospitals, power grids, railways, bridges, tunnels,

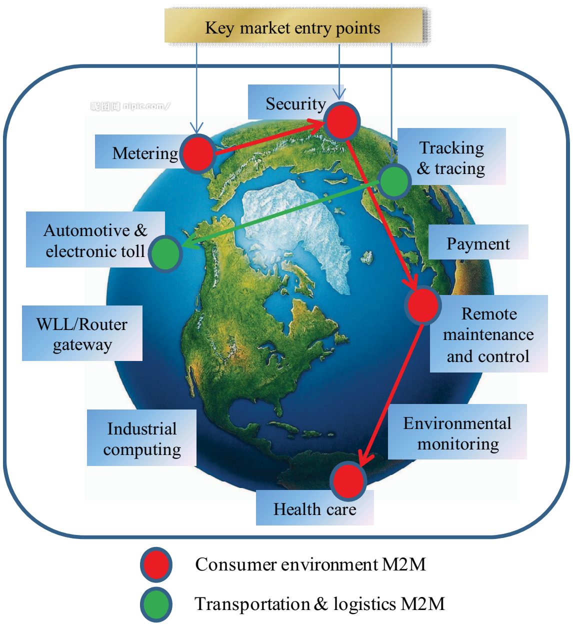

Figure 1. Potential market for M2M communications

roads, buildings, water systems, vehicles, oil and gas pipelines, and other objects in every corner of the world, and forming the internet of things (IoT) via the various networks [8]. We can realize the IoT for smart city through super computers, cloud computing, cyber-physical and M2M technologies [9, 10]. In recent years, smart city has increasingly become a reality. In spite of the development of smart city at a high rate of speed, the M2M market is currently demanding in several ways, including low prices, quality connections, longevity and easy of use.

Smart city as a huge intelligent system needs a rational architecture to effectively process mass data and then ensure the critical data. In [11], the event-driven architecture was reviewed. In this overview report, the power of event-driven architecture together with service-oriented architecture was demonstrated. To make "information" in the physical world available for smart services in embedded and ubiquitous systems, some research projects make it possible to mash-up

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and integrate information between all applications and domains spanning from embedded domains to the Web. The smart objects for intelligent applications (SOFIA) project is a three-year ARTEMIS project started in January 2009 and involving partners from four different EU countries [12]. The main goal of the SOFIA project is to create a semantic interoperability platform and a selected set of vertical applications to form smart environments based on embedded systems. In SOFIA, the main concepts from function perspective include semantic information brokers (SIB), knowledge-based processors (KBP) and smart space access protocol (SSAP), as shown in Figure 2.

- *SIB*. A SIB is a computer service that automatically provides semantic mapper services, and is frequently part of a semantic middleware system that leverages semantic equivalence statements.
- *KBP*. The KBP is used for processing packets in computer networks. It is very essential for the long term success of the IPv6 network. The build out of the IPv6 network is inevitable as it provides the means to an improved and secure networking system.
- *SSAP*. The SSAP is used for performing operations on the semantic net. KBP can access the information within the smart space by connecting to the SIB and invoking the operations offered by SSAP interface.

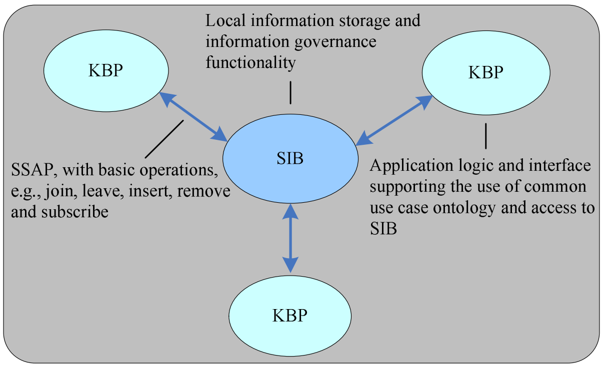

Figure 2. Functional architecture in SOFIA

In order to reasonably manage and process the critical data, we built an event-based architecture depending on SOFIA project. Based on this architecture, we carried out a case study in a vehicular context. An event processing flow for vehicle maintenance services (VMS) was designed to schedule and manage the mission-critical wireless messages. This work will promote the development of smart city from the point of view of processing critical data.

The rest of this article is organized as follows. In Section II, we introduce the new tendency in M2M development, i.e., M2M to human. In Section III, we in brief outline the typical applications and challenges in smart city. We adopt SOFIA project to build an event-based architecture in Section IV. A case study in a vehicular context is carried out in Section V. Finally, the conclusion is given in Section VI.

II. New Trend: Machine to Machine to Human

With the development of emerging technologies, such as, cloud computing, cyber-physical systems, wireless sensor networks (WSNs), networked control systems, and embedded systems, M2M communications using the IoT concept are expected to connect 15 billion devices by 2015. This offers new opportunities to connect among machines, devices, systems and people, which are called machine-to-machine-to-human (M2M2H) communications.

A. Cloud Computing for M2M Communications

In recent years, cloud computing as a very new field in internet computing has provided novel perspectives in inter-networking technologies and raised issues in the architecture, design, and implementation of existing networks and data centers. Figure 3 shows a cloud computing platform for M2M communications [5]. This platform includes three key benefits: 1) multi-tenant platform for B2B and B2C services, 2) integrating operator assets of billing, location, network and identity, and 3) ecosystem of devices and applications.

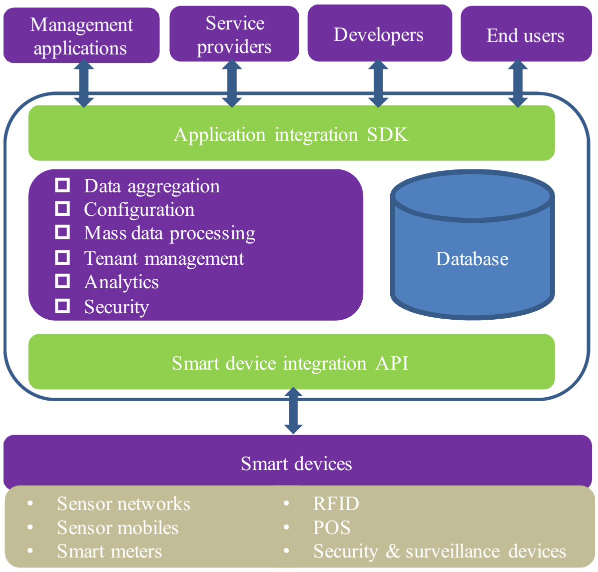

Figure 3. M2M cloud computing platform

B. M2M2H Hierarchical Configuration

Figure 4 shows the environment part may consist of diverse devices, such as computers servers for measuring and processing, HVAC (heating, ventilation, and air conditioning) system for consumption control and optimization, and fridge for controlling the temperature process and compressor [13]. M2M part consists of devices, such as: (1) temperature, pressure or motion sensors, (2) switches to control lighting, or/and (3) GSM device to communicate to the internet via networks infrastructure, such as Zigbee or WiFi or Ethernet connection having IP enabled gateway. Such a configuration enables us to remotely observe and control the environment. The communication part denotes the Internet, Intranet, GSM networks, etc.

The web applications and services part consists of web services meant to service to human equipped with machines, such as laptop and smart phone. It provides the communication between human machines and the gateway. Wireless communication devices operate at three different distances: 1) very short range (distance up to few centimeters), 2) short range (distance up to 10-15 meters), and 3) long range up to hundreds of kilometers. Generally, GPRS is used for the long range communication. M2M2H communications over the internet enable us to remotely measure various parameters and control smart devices (objects) by means of network electronic devices of consumers, such as smart phone and laptop.

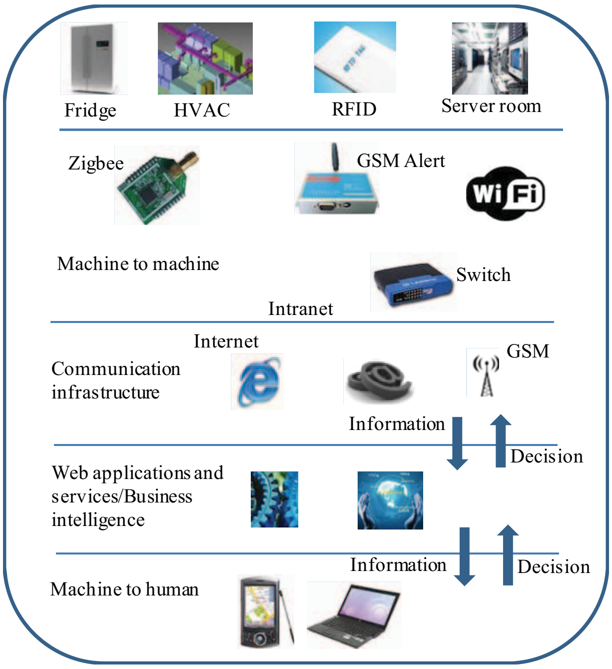

Figure 4. M2M2H hierarchical configuration in smart city

III. Application Domains and Issues in Smart City

In recent years, with the concept of "smart planet" being putted forward, smart city, smart grid, smart enterprises and remote hospital have been proposed as important parts of smart planet successively. Also, the emerging technologies, such as cloud computing, WSNs, vehicular networking and M2M communications, powerfully promote smart city to become a reality.

A. Application Domains of Smart City

Unquestionably, smart city will be the future trend of urban development. Generally, the construction of smart city can be divided into three levels: 1) the construction of application systems, 2) the construction of public platform for smart city, and 3) the construction of public infrastructure. In this three-level, the construction of application systems is particularly important, and has attracted great concern across the country. Currently, except defensing the national security applications, smart city has been typically applied to a number of aspects, such as healthcare, smart transportation, smart home, smart tourism and smart public services (e.g. smart grid). Figure 5 shows the construction frame of application systems for smart city [8].

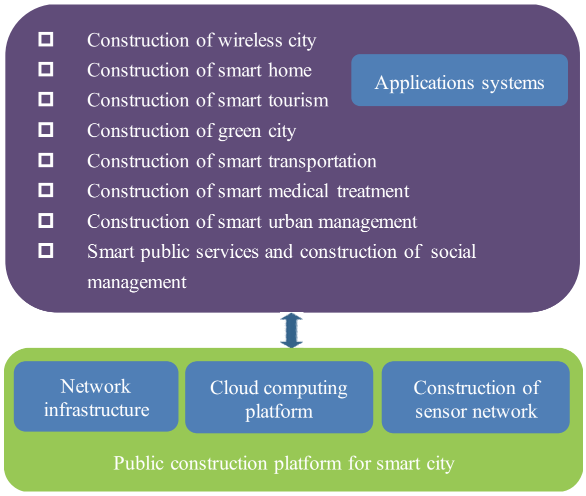

Figure 5. Construction frame of application systems for smart city

B. Issues and Challenges

Now, the extensive applications of smart city is facing great difficulties because of some potential reasons, such as the increasing needs of urban management, construction and operation in reasonable planning of urban space and function layout, detection of incident, emergency response and public information services. The following are the main issues and challenges in smart city.

- The novel network architecture and mass data fusion.
- The legal protection for sound information service and shared policy mechanism.
- The management, integration and release of massive urban spatial-temporal data.
- The large-scale space-time information and efficient services.
- The modeling analysis of heterogeneous sensor data and semantic description of the internet of things.
- The technology of intelligent analysis and decision support (e.g., data mining).
- The scheduling and management of mission-critical wireless messages to ensure reliability and real-time response.

IV. Building An Event-Based Architecture for Smart City

The main goal of smart city architecture is to provide a framework for the implementation of information services for monitoring public areas and infrastructures. In this section, we introduce the smart city high-level architecture and event manager for scheduling the crucial wireless messages.

A. *Smart City High-level Architecture*

An event-based high-level architecture for smart city is depicted in Figure 6 [14]. The main building blocks of smart city architecture are KBPs and SIBs. The KBPs are responsible to produce (insert/remove) and/or to consume (query/subscribe) notifications of event. The notifications describe events as observed locally by KBPs and decision to publish a notification is a core part of the publisher KBPs internal logic. The SIBs are used to implement a publish/subscribe paradigm, conveying notifications from producer KBPs and delivering every published notification to all consumers KBPs having registered matching subscriptions. The cooperation between KBPs and SIBs, together with suitable routing strategies, creates the interoperability open platform (IOP).

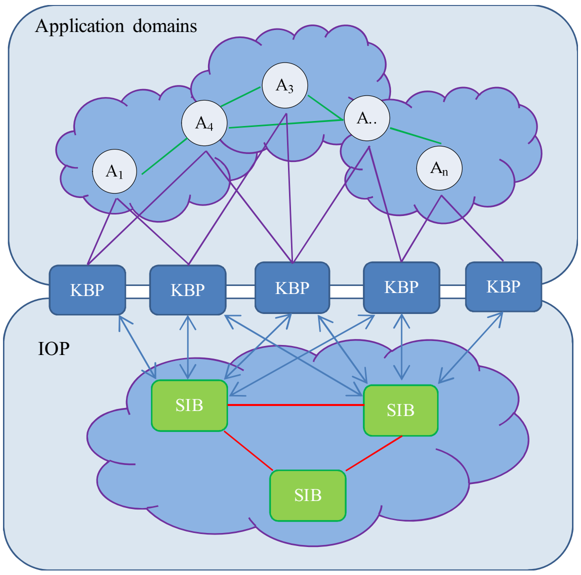

Figure 6. Smart city high-level architecture

B. *Event Manager*

The WSN subsystem includes a WSN manager and one or more WSNs. The WSN manager implements both a consumer KBP and a producer KBP so that it can interact with IOP in order to receive commands or dispatch raw events. The event manager is a very important module to merge and correlate events generated by raw data sources, such as the WSN manager. These events are correlated by means of some static criteria in order to detect anomalies in the current status of the monitored areas. The events generated by these anomalies are exchanged with other application layer modules through the SOFIA IOP. Also, the event manager can also react to some specific events, generating configuration commands.

V. CASE STUDY: M2M COMMUNICATIONS IN VEHICULAR NETWORKS

In this section, we illuminate the application of smart city exemplified by vehicular networks by means of the technology of M2M communications. The main contents include M2M network architecture in a vehicular context and VMS event processing flow.

A. *M2M Network Architecture in a Vehicular Context*

Figure 7 shows M2M network architecture for a vehicular network [13]. The architecture may be divided into five-layer according to the diverse functionality. Communications among instruments in a car is designated as intra-car communications and generally occurs on a wired CAN or MOST ring. Through high-bandwidth wireless technologies, such as Wi-Fi, V2V and V2I can easily be achieved. ITS networks endeavor to put in place intelligent and cooperative transportation infrastructures that include electronic tolling and traffic monitoring by road-based sensors. The servers and databases connected to the Internet allow end-users to remotely access various services of the vehicular network.

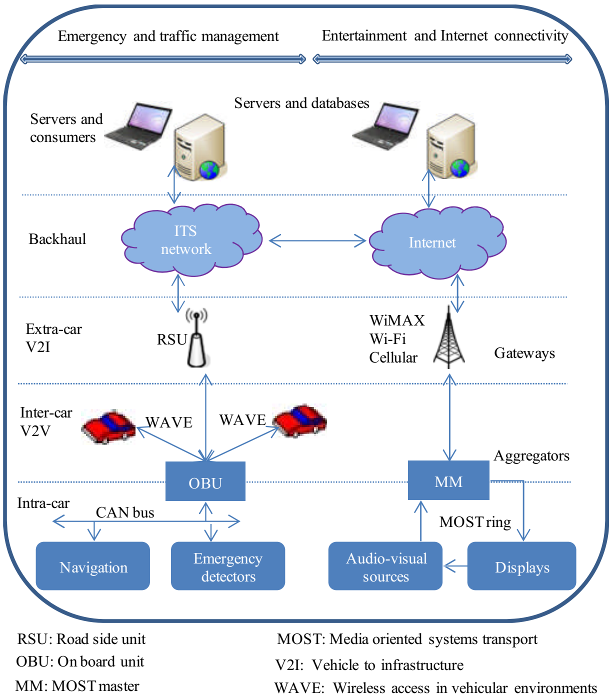

Figure 7. M2M network architecture in a vehicular context

B. *VMS Event Processing Flow*

In this subsection, we propose a VMS event processing flow developed in the context of SOFIA project. The mission-critical wireless messages are scheduled by the diverse event managers.

Figure 8 shows a possible information flow where data are aggregated and correlated, increasing at each step their level of abstraction from raw physical data (e.g., engine temperature) to high level event (e.g., unexpected nonfatal problem). A cloud of heterogeneous sensors performs measurements of the vehicle (vehicle status, problem occurring, mechanical stress, etc.). These measurements are managed by the WSN subsystem, which publishes the raw events (i.e., the measurements itself) in the SIB. The WSN subsystem might also perform local computation such as filter-out some readings or aggregate data. Raw and heterogeneous events (i.e., provided by different kind of sensors) are retrieved from the

SIB by an event correlator which performs a further step of data aggregation, according to a suitable set of rules which exploit: 1) temporal redundancy (measurements performed in consecutive periods of time), 2) spatial redundancy (measurements performed by sensor displaced in near but different locations), and 3) dimensional redundancy (measurement of a different physical dimension performed by different clouds of sensors). The result of data correlation, enriched with a reliability index which gives a score to the likelihood of the detected phenomenon, is a composite event published in the SIB. Finally, the alert announcers (e.g., automotive manufacturer and official vehicle service center) inform the end-users of dangerous and/or critical situations, exploiting effective human computer interaction techniques.

For the proposed VMS event processing flow, the reliable wireless message scheduling will ensure the reliability and real-time response. Jiang [15] established a risk-free security profit model that can quantify the security quality of security-sensitive aperiodic messages. In [16], the literature contributes with a message scheduling algorithm for mission-critical system (e.g., cyber-physical systems [17, 18]) under unreliable wireless communication model. The advantages of this algorithm are in satisfying the reliability and real-time requirements of individual message by the reliability-driven retransmitting mechanism and deadline guaranteed mechanism. Therefore, we should synthesize current wireless message scheduling algorithms with the concept of SOFIA project to manage the VMS event processing flow.

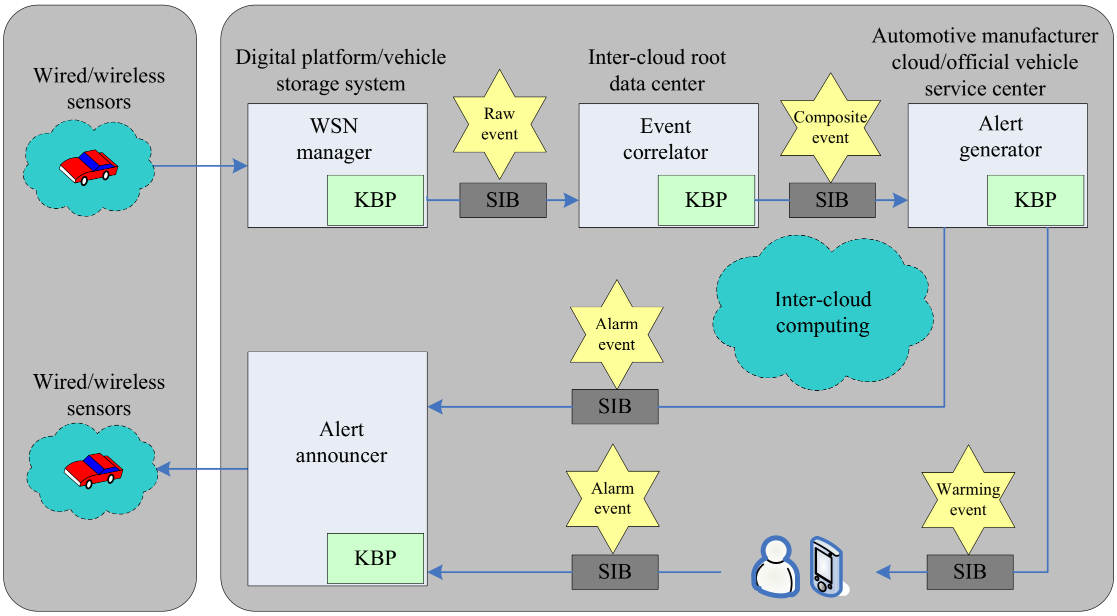

Figure 8. VMS event processing flow

VI. Conclusions

M2M communications play an important role in promoting smart city, and can be adopted in many applications (e.g., intelligent transportation, public safety, energy management, and smart grid). Many emerging technologies, such as cloud computing, WSNs and advanced control algorithms, allow smart city to become a reality. In this article, the new tendency in M2M development and the construction frame of application systems in smart city are introduced and analyzed. Then, we design an event-based architecture depending on SOFIA project to allow the management and cooperation among M2M components by event manager. Adopting this architecture, we conduct a case study in a vehicular context. The M2M network architecture for vehicular networks and an event processing flow of VMS are introduced to manage the mission-critical wireless messages. Further research on this project will take into account of scheduling wireless messages by integrating the concept of SOFIA project.

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