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From Machine-to-Machine Communications towards Cyber-Physical Systems

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Abstract. In recent years, cyber-physical systems (CPS) have emerged as a promising direction to enrich the interactions between physical and virtual worlds. In this article, we first present the correlations among machine-to-machine (M2M), wireless sensor networks (WSNs), CPS and internet of things (IoT), and introduce some research activities in M2M, including M2M architectures and typical applications. Then, we review two CPS platforms and systems that have been proposed recently, including a novel prototype platform for multiple unmanned vehicles with WSNs navigation and cyber-transportation systems. Through these reviews, we propose CPS is an evolution of M2M by the introduction of more intelligent and interactive operations, under the architecture of IoT. Also, we especially hope to demonstrate how M2M systems with the capabilities of decision-making and autonomous control can be upgraded to CPS and identify the important research challenges related to CPS designs.

Keywords: internet of things, machine-to-machine communications, wireless sensor networks, cyber-physical systems, unmanned vehicles, cyber-transportation systems, challenges

1. Introduction

In recent years, wireless and wired systems to communicate with other devices of the same ability have been one of the fastest-growing research

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areas. Significant progress has been made in many domains, such as machine-to-machine (M2M) communications, wireless sensor networks (WSNs), and wireless body area networks (WBAN) [1, 2]. Typically, M2M refers to the communications among computers, embedded processors, smart sensors, smart actuators, and mobile terminal devices without or with limited human intervention [3]. The rationale behind M2M communications is based on two observations: 1) a networked machine is more valuable than an isolated one; and 2) when multiple machines are effectively interconnected, more autonomous and intelligent applications can be generated. Therefore, the development of M2M communications generates a lot of new opportunities for information industry.

Now, the impacts of M2M communications will continuously increase in this decade according to previous predictions [4]. For example, some 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. At present, the various applications of M2M have already started to emerge in several fields, such as healthcare, smart home technologies, manufacturing systems, and smart grids [5].

Through interfacing with WSNs, M2M systems can collect a wide range of information by all kinds of sensors. Thus, in addition to M2M communications, machines also can make action through the collected information with the integration with WSNs. From a long-term point of view, M2M systems with the capabilities of decision-making and autonomous control can be upgraded to cyber-physical systems (CPS). Recently, CPS has emerged as a promising direction to enrich human-to-human, human-to-object, and object-to-object interactions in the physical world as well as in the virtual world [6].

Apparently, CPS would adopt, and even nurture, the areas of M2M and WSNs because more sensor inputs and richer network connectivity may be needed. Therefore, it is desirable to review what has been developed in these fields, project what may happen in the field of CPS, and identify what needs to be further researched. In this article, we intend to serve these purposes by identifying the unique features of M2M, raising some CPS examples, and then pointing out the future challenges of CPS. To build some foundations, we first review some existing results of M2M. This part is to provide some preliminaries of M2M and establish the necessary connections between M2M and CPS. It also helps to identify the key techniques in M2M which may be useful for CPS designs and foresee what issues and challenges need to be further researched in CPS.

Although M2M, WSNs and CPS are quite similar in many networking aspects, there are still some major differences from architecture and design philosophy. Generally, M2M is for supporting communications without or with limited human intervention. WSNs are particularly designed for delivering sensor-related data. CPS typically involves multiple dimensions of sensing data, crosses multiple sensor networks and the Internet, emphasizes control functions, and aims at constructing intelligence across multiple domains.

Thus, we propose CPS is an evolution of M2M by the introduction of more intelligent and interactive operations, under the architecture of internet of things (IoT). While the correlations among M2M, WSNs, CPS, and IoT is still not clear, we give a novel approach to illustrate their differences in this article.

The rest of this paper is organized as follows. In Section 2, we discuss related work from the literature, presenting the context for our work. In Section 3, we dissect the correlations among M2M, WSNs, CPS and IoT. Section 4 reviews the architectures and some applications of M2M, and points out the issues and challenges. In Section 5, two typical examples including a prototype platform for multiple unmanned vehicles with WSNs navigation, and a vehicle making a left-turn with cyber-transportation systems (CTS) assistance, are given to illuminate how to move from M2M to CPS. The crucial challenges of CPS are in brief outlined in Section 6. Finally, Section 7 concludes the paper.

2. Related Work

The basic concepts of M2M and CPS, and their typical applications have been the subject of many research studies recently. Both of M2M and CPS are applied to the similar domain. M2M is from the point of view of communications without or with limited human intervention. By contrast, CPS emphasizes not only communications but also distributed/real-time control and across-domain optimization. Here, we mainly focus on their research advances.

At present, the various applications of M2M have already emerged in several fields, such as intelligent transportation, healthcare, smart robots, home networks, and smart grids. In [7, 8], the network design issue of M2M communications for a home energy management system in the smart grid was analyzed, and a hierarchical smart grid architecture was designed. In [9], the architecture of home M2M networks decomposed into three sub-areas depending on the radio service ranges and potential applications were proposed. In [10-12], a dialogue agent among the sensory agent, the dialogue agent, and the decision support agent, was designed. Besides these, other applications include pollution control facilities, experiments for learning, hygienic meteorology service, integrated video services, etc [13-17]. In order to substantially reduce development costs and improve time to market, the collaboration among standards organizations across different industries is quite essential. Fortunately, the technical standardizations for M2M are proceeding in standards developing organizations such as 3GPP, ETSI, IEEE, and TIA [18, 19]. In recent years, the organizations have defined the network architectures and functions to support the unique features of M2M communications in their standard bodies.

Since the distributed/real-time control, advanced network techniques, and cloud computing are further developed, the emerging CPS has been produced in M2M research [5]. CPS has some defining characteristics as follows: 1) cyber capability in every physical component and resource constraints, 2) closely integrated, 3) networked at multiple and extreme scales, 4) complex multiple temporal and spatial scales, 5) dynamically reorganizing/ reconfiguring, 6) closed-loop control and high degrees of automation, and 7) operation must be dependable and certified in some cases [20-24]. In the last few years, some achievements have been made in the emerging CPS field, which promotes the development of CPS [25-30]. In summary, the research achievements include the several aspects, such as energy management, network security, data transmission and management, model-based design, control technique, system resource allocation, and services and applications [31]. However, a variety of issues and challenges need to be solved at different layers of the architecture and from different aspects of system design to ease the integration of the physical and cyber worlds [32].

3. Correlation Overview of Several Related Terms

3.1. WSNs, M2M, and CPS Belong to IoT

In recent years, the concept of IoT has become particularly popular through some representative applications, such as greenhouse monitoring, smart electric meter reading, telemedicine monitoring, and intelligent transportation. Generally, IoT has four major components: 1) sensing, 2) heterogeneous access, 3) information processing, and 4) applications and services, and additional components, such as security and privacy. In essence, WSNs, M2M, and CPS belong to IoT, since all of them must have the same components as above. The differences just are the proportion of the design among the four components [5].

Usually, WSNs consist of spatially distributed autonomous sensors to monitor physical or environmental conditions, and to cooperatively pass their data through a variety of networks to a main location. WSNs emphasizing the information perception through all kinds of sensor nodes are the very basic scenario of IoT. Over the past ten years, the theories and applications of WSNs have made a very big progress. The advances in wireless communication technologies, such as wearable and implantable biosensors, along with recent developments in the embedded computing, intelligent systems, and cloud computing areas are enabling the design, development, and implementation of higher level systems for IoT (e. g., CPS).

According to the concern focuses of different applications, IoT has different incarnations, such as M2M and CPS. M2M refers to technologies that allow both wireless and wired systems to communicate with other devices of the same ability. Similar with WSNs, M2M systems possess distinctive characteristics, such as support of a huge amount of nodes, seamless domain inter-operability, autonomous operation and self-organization. Under the architecture of IoT, M2M mainly concentrates machine-type-communication (MTC) that means no human intervention whilst devices are communicating end-to-end, and emphasizes the practical applications (e. g., smart home and smart grid) that are the main patterns of IoT at present. However, the intelligent information processing, such as artificial neural networks and data-fusion, and distributed real-time control, are not the main emphasis in the terms of M2M design.

Now, the ambient intelligence and autonomous control are just not part of the original concept of IoT. With the development of emerging network techniques, distributed multi-agent/real-time control and cloud computing, there is a shift that M2M research will integrate the concepts of IoT with autonomous control to produce an evolution of M2M in the form of CPS. CPS is a very complicated system featuring a tight combination and coordination between the system's computational and physical elements [21]. Generally, the wireless sensor and actuator networks are seen as the precursor of CPS. Basically, CPS focuses on intelligentizing interaction, interactive applications, cross-layer optimization, cross-domain optimization, distributed real-time control, etc. Therefore, some new technologies and methodologies should be designed to meet the higher requirements in terms of reliability, security, and privacy, and real-time performance. In short, the widespread applications of CPS require more breakthroughs in the research of theoretical and technical support.

3.2. From M2M to CPS: An Inevitable Evolution

With the development of M2M, WSNs, radio frequency identification (RFID), pervasive computing technology, network communication technology and emerging control theory, CPS as a new pattern of IoT is becoming a reality. CPS applications have the potential to benefit from massive wireless networks and smart devices, which would allow CPS applications to provide intelligent services based on knowledge from the surrounding physical world. In the future, the high-performance CPS will be a higher stage of IoT. We outline the correlations among IoT, WSNs, M2M and CPS, as shown in Table 1.

Table 1 Considered correlations among IoT, WSNs, M2M and CPS

Classification	Correlations
WSNs, M2M and CPS	All of them belong to IoT from the architecture perspective.
WSNs	WSNs are the very basic scenario of IoT and the foundation of CPS, and are regarded as the supplement of M2M.

WBAN	It is a very typical scenario of WSNs.
M2M	It is the main pattern of IoT at the present stage.
CPS	It is an evolution of M2M in intelligent information processing, and will be an important technical form for IoT in the future.
CTS	It is a quite representative scenario of CPS.

According to Fig. 1, the flat region formed by CPS, WSNs and M2M represents the IoT. In the coming years, the development of WSNs and M2M will promote the CPS applications.

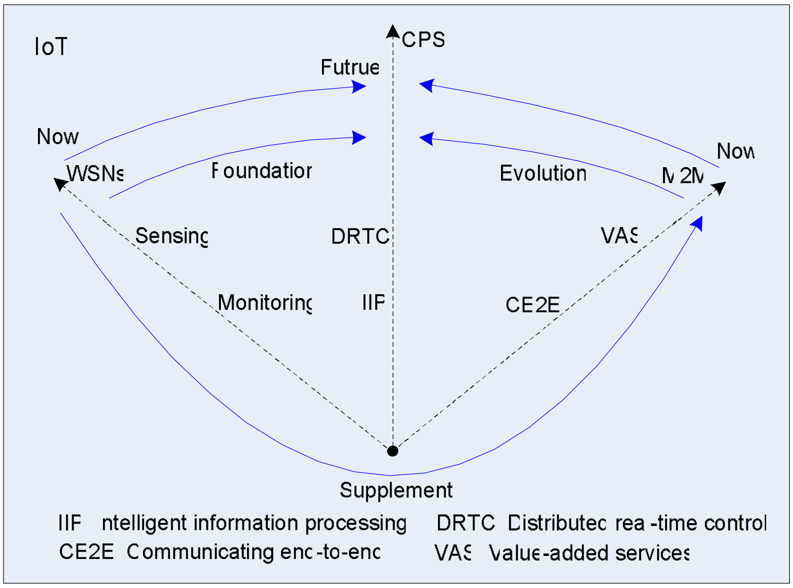

Fig. 1. Proposed correlations among M2M, WSNs, CPS, and IoT

4. Architectures and Applications of M2M

The basic architecture of M2M and its applications have been the subject of many research studies recently. Here, we focus mainly on the introduction of M2M architecture domains, the comparisons of different M2M applications, and the summarization of issues and challenges in M2M.

4.1. Architectures for M2M Communications

The applications of M2M communications extraordinarily depend on many technologies across multiple industries. Consequently, the required scope of standardization is significantly greater than that of any traditional standards development. The technical standardizations for M2M are proceeding in standards developing organizations, such as 3GPP, IEEE, TIA, and ETSI. The ETSI drafting standards for information and communications technologies considers an M2M network as a five-part structure [33]. (1) Devices, usually are embedded in a smart device and reply to requests or sends data. (2) Gateway, acts as an entrance to another network. It provides device inter-working and inter-connection. (3) M2M area network, furnishes connection between all kinds of intelligent devices and gateways. (4) Communication networks, achieve connections between gateways and applications. (5) Applications and services, pass datum through various application services and is used by the specific business-processing engines. It is a software agent analyzes data, takes action and reports data.

According to ETSI, this standardization plays an indispensable role in long term development of the M2M technology. The five elements structure proposed by ETSI forms the three interlinked domains, including M2M area domain formed by an M2M area network and M2M gateway, communication network domain consisting of all kinds of wired/wireless networks such as xDSL and 3G, and application domain [34, 35]. Fig. 2 shows M2M architecture domains.

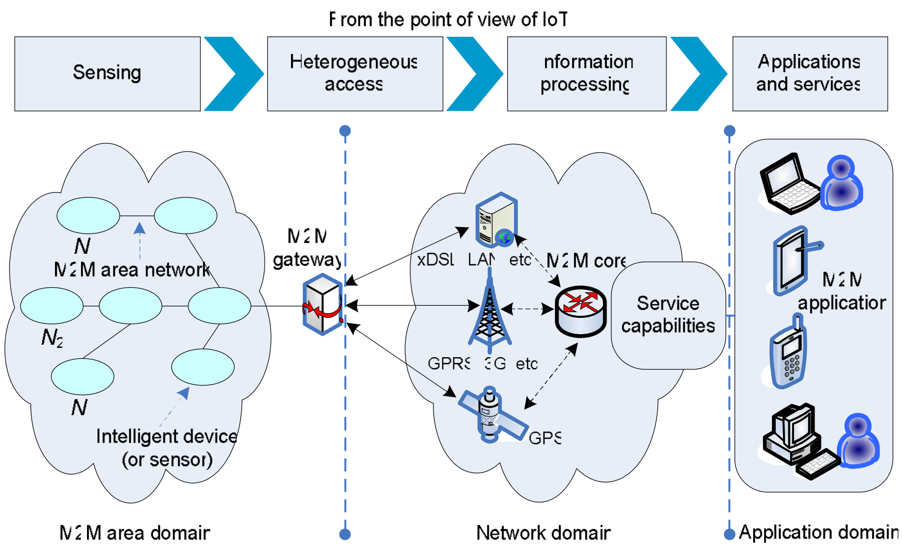

Fig. 2. M2M architecture domains

4.2. M2M Applications

In this subsection, we analyze some applications by comparison, and then give three examples (i. e., historic preservation, manufacturing systems and home M2M networks) to illuminate the good application prospects.

M2M for Historic Preservation. We propose an innovative M2M architecture for historic preservation, as shown in Fig. 3. Concretely, the architecture is divided into a number of hierarchical networks, namely, neighborhood area network (NAN), building area network (BAN), and house area network (HAN). Based on the existing standards of gateways, IP-based communications networking is p referred, which permits virtually effortless interconnections with HAN, BAN, and NAN. The location of antique with wireless sensor is determined by some location algorithms such as RSSI. Once the antique is moved over a certain range without permission, the information on the appointed identification number is passed to the heritage management center and administrator. For this M2M system, the outstanding design challenges are to hide the sensors and ensure positioning accuracy. Therefore, we adopt UWB technology to achieve accurate positioning [36].

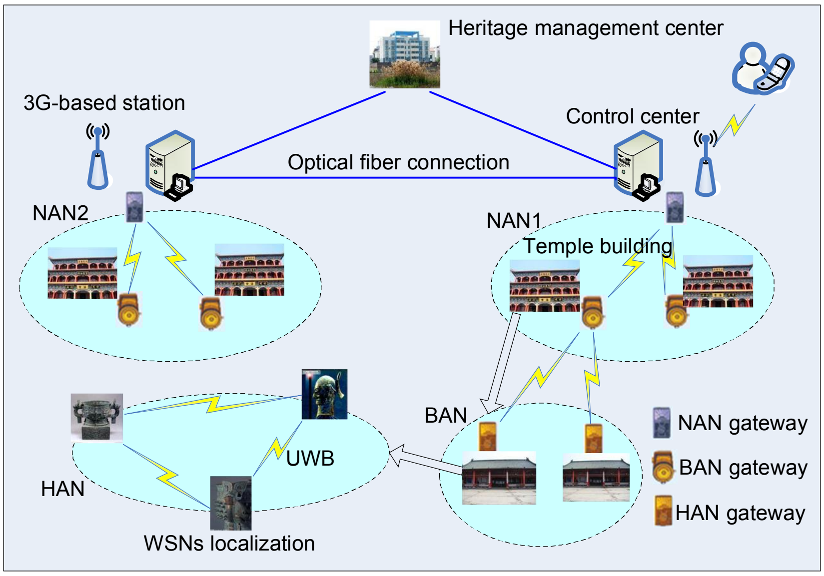

Fig. 3. Proposed M2M architecture for historic preservation

M2M for Manufacturing Systems. In the near future, the predictable improvement in machine tools will be in the form of a knowledge evolution-based intelligent device. Machine tools have always been regarded as objects of integration, but if intelligence technologies for knowledge evolution are further developed, it is expected that they may be the subject of cooperation. Fig. 4 shows the outline of a M2M environment that could be expected to minimize the roles of human experts and even to substitute for mechanical experts [12]. Machine-dependent knowledge and machine-independent knowledge are examples of types of information exchange in an M2M environment. The information may make evolution of knowledge possible with the exchange of information in real time with computer-aided manufacturers, tool makers and marketers, material producers and marketers, remote service distributors, and even e-machines. This innovation increases efficiency and saves cost.

M2M for Home Networks. In [9], a feasible architecture for home M2M network is proposed. This network architecture is decomposed into three complementary M2M structures, including home networking, health care and smart grid. The main features and promising applications in each subnetwork are identified as shown Fig. 5.

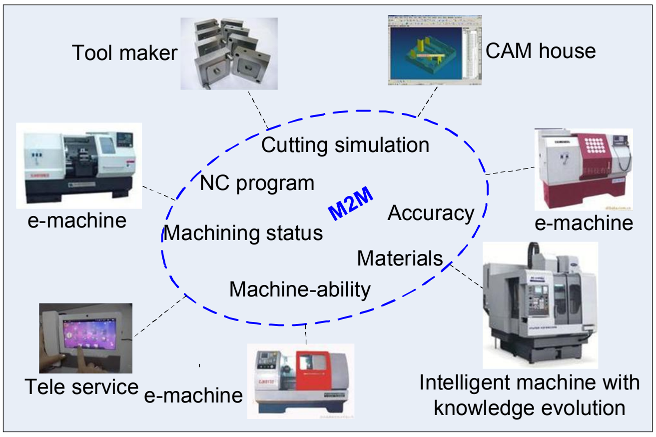

Fig. 4. M2M architecture for manufacturing systems

The home M2M network is essentially a heterogeneous network that has a backbone network and multiple sub-networks. In the backbone network, there is a central machine home gateway that manages the whole network and connects the home network to the outside world (e. g., Internet). The network-related functionalities are implemented in the home gateway, including access control, security management, QoS management, multimedia conversion, etc. Each sub-network operates in a self-organized manner and may be designed for a specific application. Each sub-network has a sub-gateway as an endpoint to connect the sub-network to the home gateway and the backbone network. Both home gateway and sub-gateway are logical entities, and their functionalities can be physically implemented in a single device (i.e., cognitive gateway).

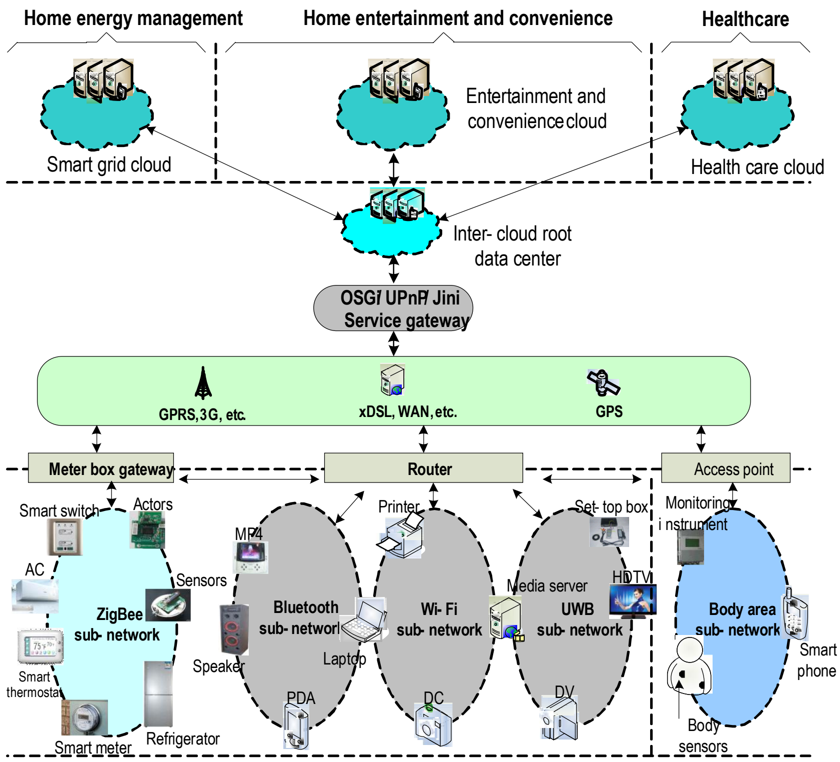

Fig. 5. M2M for smart grid, home networking, and health care

4.3. Issues and Challenges of M2M Communications

Potential Problems of M2M Case Studies in implementation. In recent years, the standards developing organizations (e.g., 3GPP and ETSI) have defined the network architectures and functions to support the unique features of M2M communications in their standard bodies. 3GPP defines features and requirements for MTC. ETST define functional and behavioral requirements of each network element to provide an end-to-end view. From the user's perspective, avoiding mutually incompatible standards will promote the popularization application.

In subsection 4.2, we in brief introduce three classic M2M applications. The key requirements of M2M technology applying to these examples are as follows:

– M2M for historic preservation. For this system, the mehtods for hiding the sensors in the antique, and especially ensuring the positioning accuracy in the indoor environment are the crucial design challenges. In actuality, since the nonline-of-sight (NLOS) error directly affects the localization accuracy, NLOS error mitigation, as a common problem, should be optimized and verified.

- M2M for manufacturing systems. The information exchanged between control devices, such as motors and actuators, needs to be secured. When parts of machine are out of order, M2M manufacturing system needs to dynamically adapt its manufacturing capability, and it also needs to switch to safe mode. Therefore, the high reliability of manufacturing systems must be guaranteed.
- M2M for home networks. The rational network architecture and energy-saving smart nodes are our biggest concerns. In implementation, we also should consider the short-range wireless technologies (e.g., Zigbee, Wi-Fi, and UWB), as well as design methodologies (e.g., cross-layer joint design) for improving the QoS of home M2M networks.

Common Challenges of M2M Systems. Now, M2M is still a very active new field, so the technology is beset with several significant challenges. The following common problems need to be addressed:

- The development of cloud computing will generate a new chance to M2M applications. However, how to seamlessly integrate cloud computing with M2M systems needs further study.
- M2M communications will change some business processes by putting a greater amount of data in the hands of more people, thus requiring all the related companies to train employees better.
- Integrating M2M elements with one another and integrating M2M operations with larger systems will require better system integration skills.
- Creating reliable networks, particularly complex mesh networks, for M2M systems could be complex and expensive.
- Security is another important issue, as users do not want hackers to break into M2M applications designed to control, for example, building security or environmental control systems. However, M2M applications generally use just the security provided by their networks.
- During the design of M2M, each node with the features such as low-cost, low-complexity, low-size, and low-energy typically consists of the following basic elements: sensor, radio chip, microcontroller, and energy supply. Maintaining long-running operation requires faultlessly solving the problem of energy supply.
- External interference is often neglected in protocol design. However, interference has major impact on link reliability. MAC and routing protocols are often channel-agnostic, and wireless channels yield great uncertainties. Routing protocols assume perfect location knowledge, but in fact, a small error in position can cause planarization techniques to fail.
- The cellular community deals with the management of huge amounts and do not disturb existing nodes. Moreover, as off-the-shelf hardware introducing some uncertainties is usually adopted, the optimization requires an innovative methodology.

5. Moving from M2M to CPS: Applications and Platforms

Since advanced control techniques, cloud computing, emerging network technologies, embedded systems, and WSNs are further developed, CPS as an evolution of M2M has been produced in M2M applications and research. CPS has the ability to bridge the cyber world (e.g., information, communication and intelligence) to the physical world through lots of sensors and actuators. A CPS may consist of multiple static/mobile sensor and actuator networks integrated under an intelligent decision system. For each individual WSN, the issues such as network formation, network/power/mobility management, and security would remain the same. However, CPS is featured by cross-domain sensor cooperation, heterogeneous information flow and intelligent decision/ actuation. The CPS architecture model is illustrated in Fig. 6.

In this section, we propose a prototype platform for multiple unmanned vehicles with WSNs navigation in the form of CPS, analyze a CTS example that takes a multi-disciplinary approach to combine cyber technologies, transportation engineering and human factors, and then compare M2M communications with CPS.

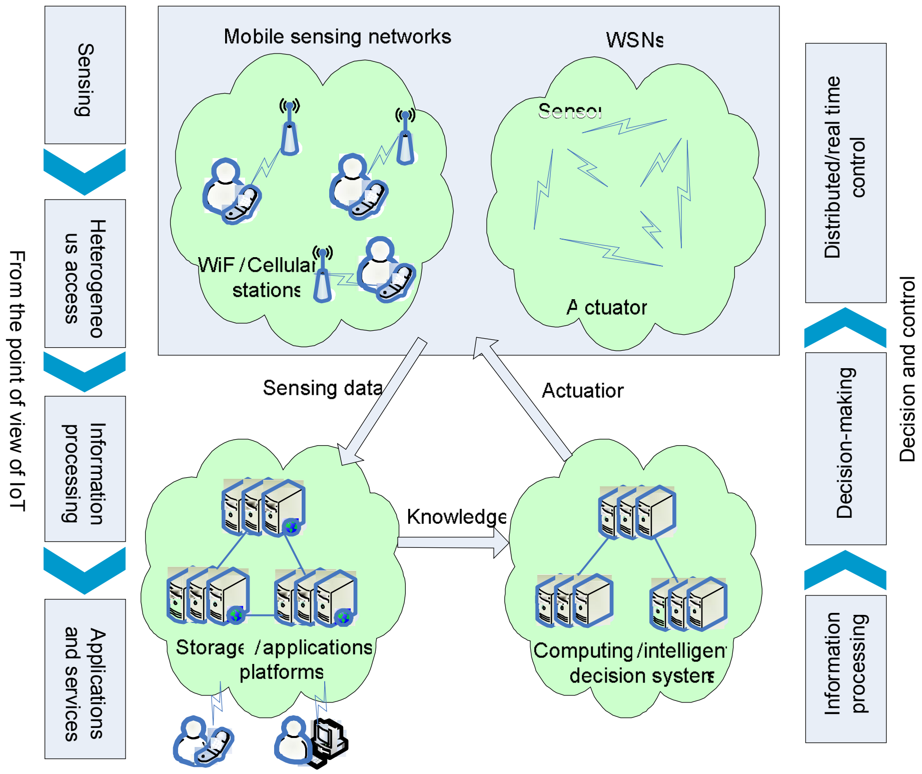

Fig. 6. A CPS architecture model

5.1. Multiple Unmanned Vehicles with WSNs Navigation

With the development of WSNs, distributed real-time control, embedded systems, mobile agent, and M2M communications, some new solutions may be applied to unmanned vehicles. A research program with the integration of intelligent road and unmanned vehicle in the form of CPS is being tested by our research group, which essentially involves M2M technology [37]. Fig. 7 shows a case of CPS, namely, a prototype platform for multiple unmanned vehicles with WSNs navigation. Currently, the application of this proposed platform is being conducted through miniature prototypes, and little work is focused on their practical implementations.

Platform Architecture. The architecture is mainly made up of WSNs, unmanned vehicle, and M2M communications. Some sensor nodes construct wireless networks with the features of dynamic reorganization and reconfiguration. The unmanned vehicles with sensor nodes get real-time datum from WSNs and further process information to determine the current behavior of vehicles. An unmanned vehicle consists of a vision system, GPS, main body mainboard, and so on. The GPS and vision system only serve as auxiliary location. The unmanned vehicles mainly achieve navigation function depending on real-time localization of WSNs [38-40].

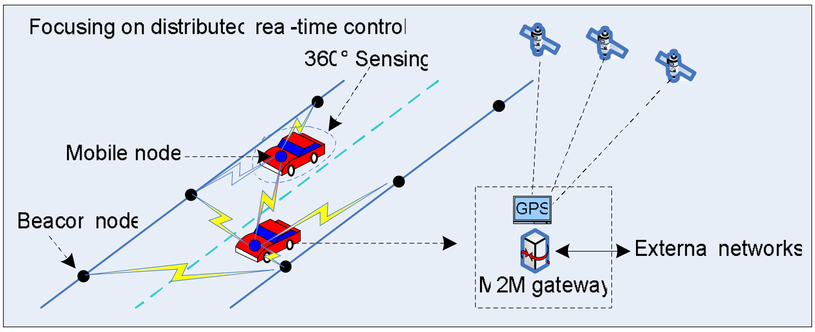

Fig. 7. A case of CPS: multiple unmanned vehicles with WSNs navigation

Navigation Principle. The navigation of unmanned vehicle is realized by computing the locations of the beacon nodes and mobile node. Via WSNs navigation, the unmanned vehicles can freely move anywhere on the flat surface. Assume that the unmanned vehicle moves from a starting point to an ending point. Before the experiment, the location information about the ending point should be sent to the unmanned vehicle that conducts path planning to determine an optimizing trajectory. In the process of running, wireless sensor nodes belonging to the unmanned vehicle exchange real-time data with the nearby beacon nodes. This way, the use of dynamic programming achieves a rational trajectory. According to the current position of the unmanned vehicle, the wireless sensors for communications continually switch. If a sensor goes wrong, this fault is solved by the recurring reorganization and reconfiguration of WSNs.

Path Planning for Unmanned Vehicle. Path planning problems arise in such diverse fields as intelligent transportation system, robotics, assembly analysis, virtual prototyping, and manufacturing. They generally involve computing a continuous sequence ("a path") of configurations (generalized coordinates) between an initial configuration (start) and a final configuration (goal) while respecting certain constraints. Through the analysis of real-time signals, we propose an innovative path planning for saving time and energy. This scheme consists of several important factors, such as severity of traffic congestion, statistical traffic situation, and the shortest path.

if UVPlanningTimerOccur(UVNumber) **then**
Position = GPS-Locating ();
OptionalPath = SelectPotentialPath(Position, End);
(Congestion, Statistic) = Get-Status (OptionalPath);
W= WeightAnalyzing (**Congestion**, **Statistic**);
if Determine (PlanningMode ())=*ExpectedCondition*
then Planing(***W***, ***Expected***);
if Determine(PlanningMode())=*AutoRecommended*
then Planing(*W*, *Recommended*);
end if

The boldfaced words are the vectors except for "**if**" and "**then**". Once the timer for path planning is triggered, the current position information of unmanned vehicle is achieved by GPS location and the potential paths are calculated according to graph theory. Then, the real-time path situation such as *congestion* and *historical statistic* of each potential path is obtained by means of cloud service. Function *WeightAnalyzing (**Congestion**, **Statistic**)* gives a weight coefficient ***W*** of a different impact factor. If the return value of function *Determine (PlanningMode())* is *ExpectedCondition*, function *Planing (**W**, **Expected**)* will calculate the path depending on given parameters. In addition, the function *Planing (**W**, **Recommended**)* automatically gives a recommended optimization path.

5.2. A Vehicle Making a Left-turn with CTS Assistance

Research Motivation of CTS. In recent years, vehicular ad-hoc network (VANET) has become a reality by using a moving car as node in a network to create a mobile network. VANET may be regarded as an example of M2M applications. In this article, we propose CTS is a special scenario of CPS, and is an evolution of VANET by integrating more intelligent and interactive operations. The design of CTS takes a multi-disciplinary approach that combines cyber technologies, transportation engineering with human factors, as shown in Fig .8 [41]. CTS is helpful for improving road safety and efficiency using cyber technologies such as wireless technologies and distributed real-time control theory.

At present, the research for CTS focuses on the following two aspects: 1) design and evaluate new CTS applications for improved traffic safety and traffic operations, and 2) design and develop an integrated traffic-driving-networking simulator [42]. To improve traffic safety, we must develop and evaluate novel algorithms and protocols for prioritization, delivery and fusion of various warning messages. At the same time, the next generation traffic management and real-time control algorithms for both normal and emergency operations (e.g., during inclement weather and evacuation scenarios) should be designed.

In addition, as the design and evaluation of CTS applications requires an effective development and testing platform integrating human, and transportation with cyber elements, a simulator that combines the main features of a traffic simulator, a networking simulator and a driving simulator needs to be developed. The integrated simulator will allow a human driver to control a subject vehicle in a virtual environment with realistic background traffic, which is capable of communicating with the driver and other vehicles with CTS messages. Fortunately, the current technological theories of WSNs, embedded systems, cloud computing, and distributed real-time control gradually support the design requirements of CTS.

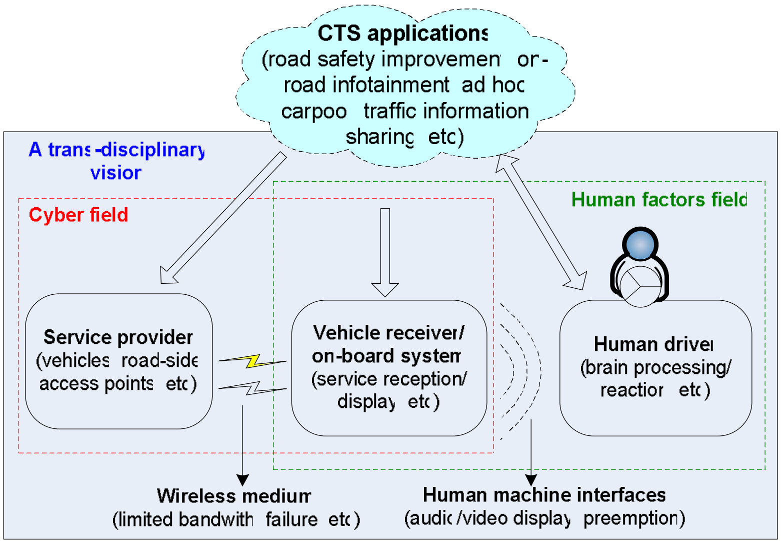

Fig. 8. CTS: An evolution of M2M communications

A Vehicle Making a Left-turn with CTS Assistance. Fig. 9 shows an example of CTS applications for a vehicle that makes a left-turn with CTS assistance [41]. Once the intersection controller detects the approaching hazard vehicle *A*, it immediately broadcasts an intersection violation warning. On the other road, the first vehicle *B* making a left-turn slams the brakes causing hard braking warnings. Meanwhile, the second vehicle *C* also slams the brakes. From sensing to execution, the process must be finished in a short span of time. Therefore, the efficiency of this system particularly depends on the real-time capabilities.

Potential Problems in Implementation. The performance of this system is affected by many factors, such as network response time, processing power of embedded systems, and cooperation abilities of multiple vehicles. Once a hazard happens, the driver or automatic system needs to insure the prompt response by slamming the brakes. If an automated braking system is used to stop or slow down, then how to select the brake degree is very crucial. From the information transfer perspective, we should establish a new message process mechanism to schedule the important messages in order to improve the responsiveness. In a word, the potential problems and challenges of CTS design include emergency vehicle routing, dealing with extreme-events and failures (failure-safe to failure operational), security and privacy, etc.

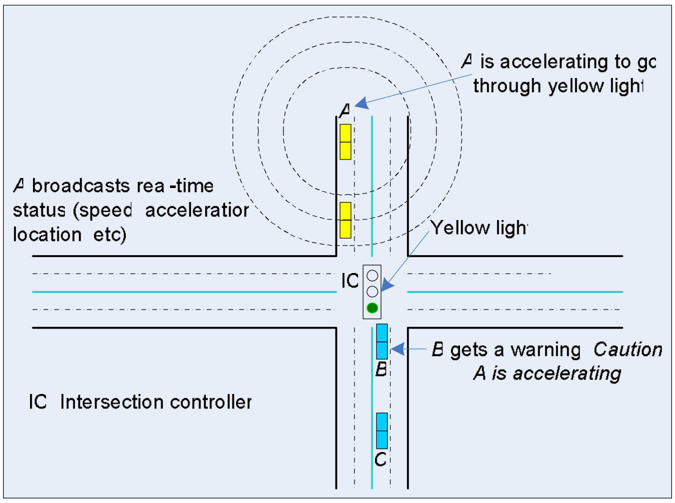

Fig. 9. A vehicle making a left-turn with CTS assistance

5.3. Comparison of M2M and CPS

Comparison Criteria. We have reviewed some typical application systems in M2M and CPS. A CPS application may bridge multiple remote WSNs and take actions. Data from such applications is expected to be continuous streaming data at a very large volume, therefore the storing, processing, and interpreting these data in a real-time manner is essential. In order to compare

M2M with CPS, we consider the concepts of M2M and CPS, analyze the case studies, and further summarize the comparison criteria as follows:

- The community of M2M more focuses on supporting the autonomous communications of all kind of intelligent nodes.
- The community of CPS mainly focuses on the development of cross-domain intelligence and optimization from multiple WSNs and the interactions between virtual world and physical world.
- CPS emphasizes the closed-loop/real-time control and high degrees of automation (e.g., multiple unmanned vehicles with WSNs navigation, and CTS).
- By contrast, M2M systems stress on the connectivity without or with limited human intervention (e.g., M2M for historic preservation).
- The technical standardizations for M2M are proceeding in standards developing organizations, such as 3GPP, ETSI, IEEE, and TIA. However, the widespread applications of CPS require breakthroughs in the research of theoretical and technical support, including the development of standard research.

Qualitative Comparison of M2M and CPS. In recent years, the applications of M2M have improved human life, and the emerging CPS case (e.g., CTS) has gradually become a reality. The important factors to the success of CPS applications mainly include the management of cross-domain sensing data, embedded and mobile sensing technologies, elastic computing and storaging technologies, distributed real-time control technologies, privacy and security designs, etc. Table 2 shows a qualitative comparison of M2M and CPS.

Table 2. A qualitative comparison of M2M and CPS.

Networks/features		M2M	CPS
Communication pattern	Query-response flows	.	.
	Arbitrary communication flows	.	.
	Cross-domain communication flows		.
	Deterministic delay communication flows		.
Network formation	Random deployment	.	.
	Dynamic topology	.	.
	Time-varying deployment	.	.
	Interconnection among multiple networks	.	.
Power management	Opportunistic sleep	.	.
	Multiple sleep modes of nodes	.	.
	Power management techniques for both sensors and central servers	.	.
Network connectivity	Connectivity	.	.
	Coverage	.	.

and coverage	Heterogeneous coverage	.	.
Knowledge mining	Data mining and database management	.	.
	Multi-domain data sources		.
	Data privacy and security	.	.
Quality of services	Networking QoS	.	.
	Multiple data resolution across domain		.
Real-time feedback control	Data acquisition	.	.
	Distributed real-time/autonomous control		.
Standards	Standards developing organizations	.	

6. Issues and Challenges of CPS Designs

Nowadays, the recent research advances for CPS mainly concentrate on the several respects, including energy management, network security, data transmission and management, model-based design, distributed real-time control technique, system resource management, platforms and systems, etc [6]. As a whole, although researchers have made some progress in modeling, control of energy and security, and approach of software-based design, among others, CPS remain in the embryonic stage. A variety of issues need to be solved at different layers of the architecture and from different aspects of system design to ease the integration of the physical and cyber worlds. Currently, the existing research challenges are summarized from various viewpoints in [43-51]. Below, we in brief review the technical challenges as follows:

– Networking issues. Since CPS spans from WSNs to M2M, a lot of interworking issues have to be further resolved.
– Design and verification tools. The tools supporting the simulation and co-design, as well as achieving automatic development process from modeling to code, are necessary. Unfortunately, the existing tools are not suited for CPS design involving multiple disciplines.
– Real-time capabilities. For some CPS applications (e.g., CTS), we must ensure that the real-time performance must meet the specific application requirements. However, many factors, such as hardware platform and control methods, affect the response time.
– Cross-domain optimization. CPS applications involve the information fusion of multiple domains and hierarchical architectures. The cross-domain optimization is quite crucial for ensuring system performance.
– Cross-domain interference avoidance. Communication reliability is critical when multiple devices co-exist. For example, WiFi, Bluetooth, and Zigbee work on the same 2.4 GHz ISM band to possibly generate interference.
– QoS and cloud computing. For future CPS, it is a challenge to minimize energy consumption and maximize QoS. The cloud computing techniques

supported by ubiquitous connectivity and virtualization can greatly help in this aspect.

- Location-based services and beyond. "Locations" are the first-class knowledge in many CPS applications, such as CTS. While GPS is widely used in outdoor environments, there are increasing demands for indoor positioning technologies. At the same time, the positioning accuracy must be considered.
- Monitoring services and beyond. CPS-based monitoring services would extend to cross-WSN, cross-M2M and cooperative models. Carriers of sensors will include mobile phones, vehicles and many other tools.
- Security and privacy challenges. Since sensing data is no longer owned by local devices, security and privacy issues become more critical in CPS.
- Standards development. CPS applications depend on many technologies across multiple industries. Consequently, the required scope of standardization is significantly greater than that of any traditional standards development.
- Design support tools. Now, there are some tools for network simulation (e.g., NS2 and OPNet) and embedded system design (e.g., Matlab and Truetime). However, the existing tools are not suited for CPS design involving multiple disciplines.

7. Conclusions

In recent years, the representative applications of M2M have been attracting significant interest, and will continue to do so for the years to come. With the further development of M2M and WSNs, the emerging domain for CPS has gradually become a reality. Building CPS requires a new science of characterizing and controlling dynamic processes across heterogeneous networks of sensors and computational devices. Now, the widespread applications of CPS need more breakthroughs in theoretical research and technical support.

In this article, we analyzed the features of M2M, WSNs, CPS and IoT, and point out the correlations among them. Then, M2M architectures, typical applications, and design challenges of M2M were reviewed. On this basis, we gave two CPS scenarios (a prototype platform for multiple unmanned vehicles with WSNs navigation, and a vehicle making a left-turn with CTS assistance) to demonstrate how M2M systems with the capabilities of decision-making and autonomous control are upgraded to CPS and outlined the important research challenges related to CPS designs. Through these reviews, we hope to stimulate more technological development and progress for future CPS applications.

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