Machine-to-Machine Communications: Architectures, Standards and Applications

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Abstract

As a new business concept, machine-to-machine (M2M) communications are born from original telemetry technology with the intrinsic features of automatic data transmissions and measurement from remote sources typically by cable or radio. M2M includes a number of technologies that need to be combined in a compatible manner to enable its deployment over a broad market of consumer electronics. In order to provide better understanding for this emerging concept, the correlations among M2M, wireless sensor networks, cyber-physical systems (CPS), and internet of things are first analyzed in this paper. Then, the basic M2M architecture is introduced and the key elements of the architecture are presented. Furthermore, the progress of global M2M standardization is reviewed, and some representative applications (i.e., smart home, smart grid and health care) are given to show that the M2M technologies are gradually utilized to benefit people's life. Finally, a novel M2M system integrating intelligent road with unmanned vehicle is proposed in the form of CPS, and an example of cyber-transportation systems for improving road safety and efficiency are introduced.

***Keywords*: M2M, WSNs, CPS, IoT, CTS**

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1. Introduction

Typically, machine-to-machine (M2M) refers to the communications between 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.

The impacts of M2M communications will continuously increase in this decade according to previous predictions [3]. For instance, 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 robots, cyber-transportation systems (CTS), manufacturing systems, smart home technologies, and smart grids [4].

Through interfacing with wireless sensor networks (WSNs), a wide range of information can be collected by sensors for M2M systems. Thus, in addition to M2M communications, machines also can make action through the collected information with the integration with WSNs. With the capabilities of decision-making and autonomous control, M2M systems can be upgraded to cyber-physical systems (CPS). 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 relationship among M2M, WSNs, CPS, and IoT is still in cloud, this paper gives a novel approach to illustrate their differences.

Then, the basic M2M architecture and the progress of global M2M standards development are introduced. In addition, some representative applications (e.g., smart home, smart grid, health care, and CTS) are presented to show that M2M technologies are gradually utilized to benefit the quality of life. Finally, a novel M2M architecture in the form of CPS is produced. This architecture integrates intelligent road with unmanned vehicle and includes many challenges, such as issues of security, authentication, data integrity, and privacy. Also, an example of CTS that combines cyber technologies, transportation engineering and human factors, is reviewed [5].

The rest of this technical survey is organized as follows. In Section 2, the differences and correlations among M2M, CPS, and IoT are analyzed. Section 3 addresses the basic architecture of M2M communications and the related components. The standards for M2M communications are reviewed in Section 4. Section 5 gives several examples of M2M applications. In Section 6, a novel M2M architecture for unmanned vehicle with WSNs navigation in the form of CPS is proposed, and an example of CTS for avoiding intersection collision is introduced. Section 7 outlines the challenges for future work, and Section 8 concludes this paper.

2. IoT, WSNs, M2M and CPS

The term, IoT that refers to uniquely identifiable objects, things, and their virtual representations in an internet-like structure, was first proposed in 1999 [6]. In recent years, the concept of IoT has become particllarly popular through some representative applications (e. g., greenhouse monitoring, intelligent transportation, telemedicine monitoring, and smart electric meter reading). IoT has four major components including sensing, heterogeneous access, information processing, applications and services, and some additional components such as security and privacy. Essentially, WSNs, M2M, and CPS belong to IoT, since all of WSNs, M2M, and CPS must have the same components mentioned previously. The differences just are the proportion of the design among the four components.

WSNs consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, and to cooperatively pass their data through the network to a main location. WSNs emphasizing the information perception through all kinds of sensor nodes are the very basic scenario of IoT. 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., M2M and CPS).

Focusing on the different types of 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 system possesses 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.

At the present stage, the ambient intelligence and autonomous control are not part of the original concept of IoT. With the development of advanced network techniques, distributed multi-agent control, and cloud computing, there is a shift integrating the concepts of IoT and autonomous control in M2M research to produce an evolution of M2M in the form of CPS. CPS is a system featuring a tight combination and coordination between the system's computational and physical elements. Usually, the sensor and actuator networks are seen as the precursor of CPS. Basically, CPS focuses on intelligentizing interaction, interactive applications, and even distributed real-time control. Therefore, some new techogies and methodologies should be developed to meet the higher requirements in terms of real-time performance such as low-jitter and low delay. In a word, the widespread applications of CPS require more breakthroughs in the research of theoretical and technical support. In the future, the high-performance CPS will be a higher stage of IoT.

With the development of WSNs, radio frequency identification (RFID), pervasive computing technology, network communication technology, and distributed real-time control theory, CPS, an emerging form 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. The following characteristics among Iot, WSNs, M2M and CPS are briefly summarized.

- WSNs, M2M, and CPS belong to IoT.
- WSNs are the very basic scenario of IoT.
- WSNs regarded as the supplement of M2M are the foundation of CPS.
- CPS is an evolution of M2M in intelligent information processing.
- M2M is the main pattern of IoT at the present stage.
- CPS will be an important technical form for IoT in the future.

Fig. 1 shows the correlations among M2M, WSNs, CPS, and IoT. The space formed by three axes (i. e., CPS, WSNs, and M2M) represents the IoT. As time goes on, the development of WSNs and M2M will promote the widespread applications of CPS.

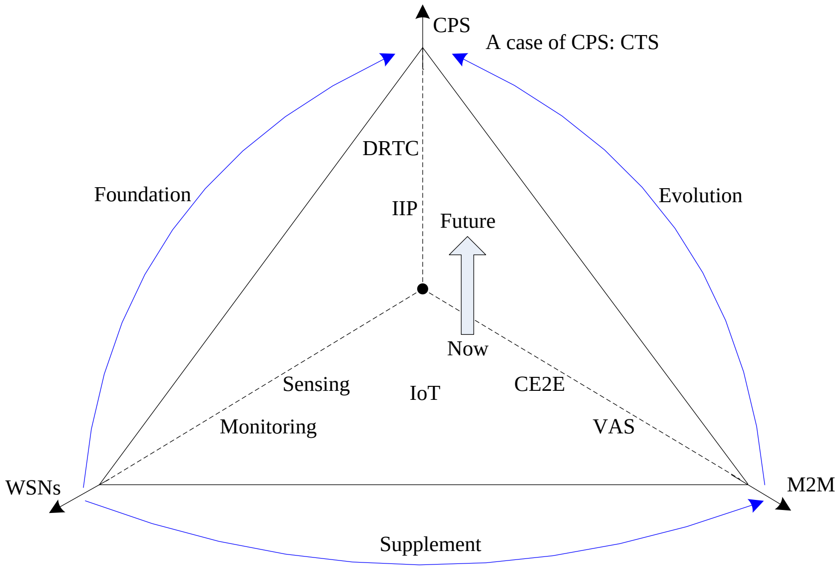

Fig. 1. Correlations among M2M, WSNs, CPS, and IoT

3. Architectures for M2M Communications

The European Telecommunications Standards Institute (ETSI) drafting standards for Information and Communications Technologies (ICT), considers an M2M network as a five-part structure [7]. (1) Devices, usually embedded in a smart device and replies 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 (or sensors) and gateways. (4) Communication networks achieve connections between gateways and applications. (5) Application, passes 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.

Examples of M2M area networks mainly include personal area network technologies, such as IEEE 802.15, Ultra-wideband (UWB), Zigbee, and Bluetooth, or local networks, such as power line communication (PLC), Wi-Fi, Femtocell, and wireless M-BUS. M2M area network (e.g., personal area network) caters to special applications and possibly adopts the same technologies applied to ad hoc and heterogeneous networks [8]. The main technologies for M2M area network are listed in **Table 1**.

The communication networks between M2M gateways and applications can be further broken down into access, transport, and core networks. The examples include, but are not limited to, xDSL, WLAN, satellite, GSM, GPRS, CDMA2000, worldwide interoperability for microwave access (WiMAX), long term evolution (LTE), and LTE-M. The short-range system and the long-range system (generally called capillary M2M and cellular M2M, respectively) will likely coexist until (almost) full migration to the cellular system has been achieved.

Table 1. Technologies for M2M area network

Standard	**Area**	**Rate** (Mbit/s)	**Energy-constrained**	**Typical applications**
SRD	Personal area	<0.02	No	Wireless audio, RFID
UWB	Personal area	>100	No	Video, files sharing
Zigbee	Personal area	<0.25	Yes	Sensors, monitoring
Bluetooth	Personal area	3.00 (V2.0)	Yes	Music sharing
PLC	Local area	>4.5	No	Smart power grid
M-BUS	Local area	<0.0096	No	Consumption meters
Wi-Fi	Local area	108 (802.11g+)	No	Water metering
Femtocell	Local area	>7.2	No	Cellular phones

According to ETSI, the technological 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: (1) M2M area domain formed by an M2M area network and M2M gateway, (2) communication network domain consisting of all kinds of wired/ wireless networks such as xDSL and 3G, and (3) application services [9] [10]. **Fig. 2** shows domains of M2M architecture.

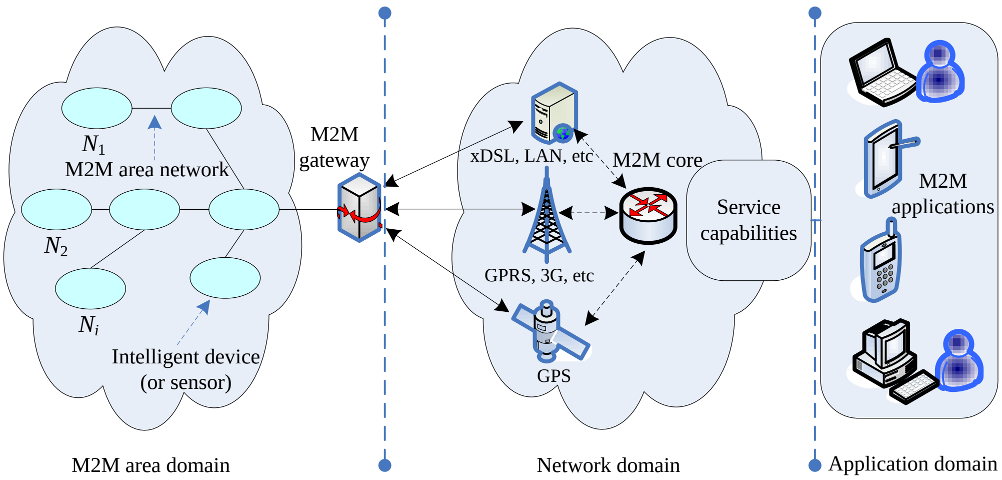

Fig. 2. M2M architecture domains

M2M devices consist of a large number of M2M nodes $\{N_1, N_2, \ldots\}$ and an M2M gateway to form an M2M area domain. Each M2M node N_i is a very flexible and smart device equipped with some specific sensing technologies (e. g., wearable wireless node in an e-healthcare system) for real-time monitoring. Once monitoring data are sensed, M2M nodes will make an intelligent decision and transmit the sensory data packets to the gateway in singlehop or multihop patterns. After collecting the packets from all kind of M2M nodes, the M2M gateway intelligently manages the packets and provides efficient paths for transmitting these packets to the remote back-end server via network domain.

In the network domain, the great success of wired networks (e. g., xDLS, and PLC) and the ubiquity of wireless networks (e.g., 3G cellular, WiMAX, and Wi-Fi) provide cost-effective and reliable channels for transmitting the sensory data packets from M2M area domain to server and application domain.

In the application domain, the back-end server is an important component for the whole M2M paradigm, which not only forms the data integration point for storing all sensory data from M2M area domain, but also provides these real-time data to a variety of M2M applications for remote monitoring management. For example, the typical utilizations are employments of global position system (GPS) data by traffic monitoring systems such as traffic court or reaction of a real-time system to its environment events.

4. Standards for M2M Communications

M2M communications 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 (SDO) such as 3GPP, ETSI, IEEE, and telecommunications industry association (TIA). In recent years, the organizations have defined the network architectures and functions to support the unique features of M2M communications in their standard bodies. The scope of various standard organizations active in M2M communications is listed in **Table 2** [11].

3GPP defines features and requirements for MTC. In [12], 3GPP also identifies two MTC scenarios, namely, MTC devices communicating with one or more MTC servers and with other MTC devices. Concretely, the networks operator provides network connectivity to MTC servers, and MTC devices can directly communicate without intermediate MTC servers, respectively. However, this scenario does not consider current standards (Release 12). Meanwhile, 3GPP introduces the key issues and solutions to fulfill the MTC service requirements in [13]. The key issues mainly focus on lack of IP addresses and congestion of control and data signals for a large number of MTC devices. The solutions try to resolve the key issues using IPv6 address or dual-stack address and group-based management for M2M devices.

ETSI focuses on the service middleware layer to be independent of access and network transmission technologies. It classifies service capabilities to provide common function required by different M2M applications. IEEE 802.16 standardizes the air interface and related functions associated with wireless local loop. It defines the aggregation point for non-802.16 or other 802.16 M2M devices [14].

According to the technological development, the cellular generations are listed in **Table 3** [15]. Both LTE and WiMAX are regarded as beyond 3G systems but are not 4G strictly speaking because they do not meet the requirements set out by the international telecommunication union for 4G next generation mobile networks (NGMN). NGMN requires downlink rates of 100 Mbps for mobile and 1 Gbps for fixed-nomadic users at bandwidths of around 100 MHz, which is the prime design target of LTE Advanced and WiMAX II. Therefore, although LTE is wrongly but understandably marketed as 4G, it is not because LTE-A is needed. In addition, the standards pertinent to capillary M2M mainly include IEEE, internet engineering task force (IETF), WirelessHart, ISA, DASH7, etc. The related standards for capillary M2M are given in **Table 4**.

In order to substantially reduce development costs and improve time to market, the collaboration among standards organizations across different industries is essential.

Fortunately, the M2M communities are starting to recognize this need, and joint efforts and collaborations among standards bodies are increasing. They draw up open interfaces and standard system architectures, and also establish a set of common software and hardware platforms. Since most existing proprietary vertical M2M solutions experience difficulty in scaling, the horizontal developments in the M2M industry are essential for realizing the embedded internet vision. This development is particularly important to consumers or home M2M applications, where the biggest market growth is yet to come.

With the development of WSNs, RFID, cloud computing, and distributed real-time control technology, CPS as an evolution of M2M is springing up in some applicatons such as CTS and unmanned vehicle with WSNs navigation. In these scenarios, the performances particularly depond on innovative technologies and methodologies, which require that standard organizations cooperate more closely.

Table 2. Standards for M2M communications

SDO	M2M development
3GPP	Release 12: Study network improvements for MTC device to MTC device communications via one or more PLMNs (direct-mode communication between devices is out of scope), etc. Align also with ETSI Technical Committee M2M work
ETSI	M2M network architecture: define functional and behavioral requirements of each network element to provide an end-to-end view ETSI TR 103 167 V1.1.1: threat analysis and counter-measures to M2M service layer
IEEE	802.16p (WiMAX): optimize air interface for low power, mass device transmission, small bursts, and device authentication; future topics: M2M gateway, co-operative M2M networks, advanced M2M features 802.11 (WiFi): update air interface to enable use of sub-GHz spectrum 802.15.4 (Zigbee): air interface optimization for smart grid networks
TIA	TR50: develop and maintain access to agnostic interface standards for monitoring and bi-directional communication of events and information between smart devices and other devices, applications, or networks
GSMA	GSM operation for M2M: define a set of GSM-based embedded modules that address operational issues, such as module design, radio interface, remote management, UICC provisioning and authentication, and basic element costs; also define use-cases in vertical markets, such as health, utilities, automotive, and consumer devices
WiMAX Forum	Network system architecture specification: define usages, deployment models with low OPEX, functional requirements based on IEEE 802.16 protocols, and performance guidelines for end-to-end M2M system
WFA	Smart grid task group: promote the adoption of Wi-Fi within the smart grid through marketing initiatives, government and industry engagement, and technical/certification programs; Healthcare task group: maintain Wi-Fi as the preferred wireless access technology and increase adoption in the Home and Hospital Healthcare market segment
OMA	Device manageability: define requirements for the gateway-managed object
CCSA NITS	CCSA TC11: focus on promoting applicaion of mobile internet, and drafting the standards for hardware interfaces of smart terminals and location-based services NITS WGSN: focus on sensor network interface and data format, ID and security, and vertical applications including airport and smart buildings

Table 3. Cellular generation

Generation	Standard
2G Networks	GSM, IS95
2.5G Network	GPRS
3G Networks	EDGE, UMTS, CDMA2000, WiMAX
3.5G Network	HDxPA
“3.9G” Network	LTE
4G Networks	LTE-A, WiMAX II

Table 4. Related standards for capillary M2M

Standard	Families
IEEE	IEEE 802.15.4, e.g., used by Zigbee
	IEEE 802.15.1, e.g., used by Bluetooth
	EEE 802.11, e.g., used by Wi-Fi
IETF	6LoWPAN (IPv6 over low-power WPAN)
	ROLL (Routing over low-power and lossy networks)
	CoRE (Constrained restful environments)

5. Representative M2M Applications

5.1 Application Domains

The basic application architecture of M2M is described in Section 3. M2M applications include intelligent transportation, heathcare, smart grid, manufacturing, supply and provisioning, and so on, as shown in **Table 5**. At present, some application cases for M2M have been conducted in [3][16][17][18][19][20]. In this article, the examples (e. g., home networking, health care, and smart grid) are used to illuminate the representative applications of M2M and present a bright future.

Table 5. M2M application domains

Domain	Applications
Security	Surveillance applications, alarms, object/people tracking
Transportation	Fleet management, emission control, toll payment, road safety related to activities in TC ITS
Heathcare	Related to e-health and personal security
Utilities	Measurement, provisioning, and billing of utilities, such as oil, water, electricity, heat, and others
Manufacturing	Production chain monitoring and automation
Supply and Provisioning	Freight supply, distribution monitoring, and vending machines
Facility Management	Home, building, and campus automation

In the M2M market, the projections on the number of connected objects differ widely [15]. The Wireless World Research Forum predicts that by 2017, there will be around 7 trillion devices connected; and ABI Research estimated in 2010 that there will be 225 million objects connected by a cellular link by 2014. The M2M market situation is given in **Table 6**.

Table 6. M2M market situation

Zone	Application service providers	Starting time	Classic applications	Co-operative corporations
Europe	Orange	2004	Vehicle system control	eDvice, Wavecom
	Vodafone	2002	Logistics	Wavecom, Nokia
Japan	Docomo	2004	Network appliance	NEC
America	Sprint, Verizon	2004	e-market	OPTO 22, Moto
China	China Telecom	2007	Smart home	ZTE
	China Mobile	2006	Transportation system	Huawei
	China Unicom	2006	Earthquake monitoring	Moto, SK

5.2 M2M Networking Applied in Home Networking, Health Care, and Smart Grid

A possible architecture for home M2M network is proposed in [17]. The network architecture is decomposed into three complementary M2M structures: home networking, health care, and smart grid (see **Fig .3**). The main features and promising applications in each subnetwork are identified. 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, and multimedia conversion. 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).

5.2.1 Home Networking

The main purpose of home networking is media distribution, but home networking can also include elements of the smart grid as described later. Media distribution systems include media storage (media server), media transportation (Wi-Fi, Bluetooth, UWB) and media consumption (high definition television (HDTV), smart phones, tablet computers, desktop computers). Home networking is currently receiving significant attention as an M2M network. A home network is composed of various smaller home device sub-networks. Each sub-network can contain an aggregator that in turn connects to the Internet gateway (router). Examples of such sub-networks are Zigbee sub-networks (electrical appliances, air conditioner (AC)), Wi-Fi sub-networks (laptop, printer, and media server), UWB sub-networks (HDTV, camcorder), smart grid sub-networks (smart meters, smart thermostat, smart switch), body area sub-network (smart phone, monitoring instrument, body sensors) and Bluetooth sub-network (music center, portable audio player). Possible aggregators include a cellular phone for the body area subnet and power meters for the smart grid subnet.

Devices exist in the home that can be connected to the Internet to provide extra services to consumers. One example where the M2M paradigm might be employed is where a fridge in a home forms part of an M2M network. The fridge is able to collect data about the number and state of items that it contains, for example the number of eggs that remain and the amount of milk a container has. Many fridges can then be connected, via the Internet and their respective home routers, to report on stock numbers and states. The reporting can be done to a grocery store chain, which can run a dispatch chain that will replenish food items in all the houses that it oversees.

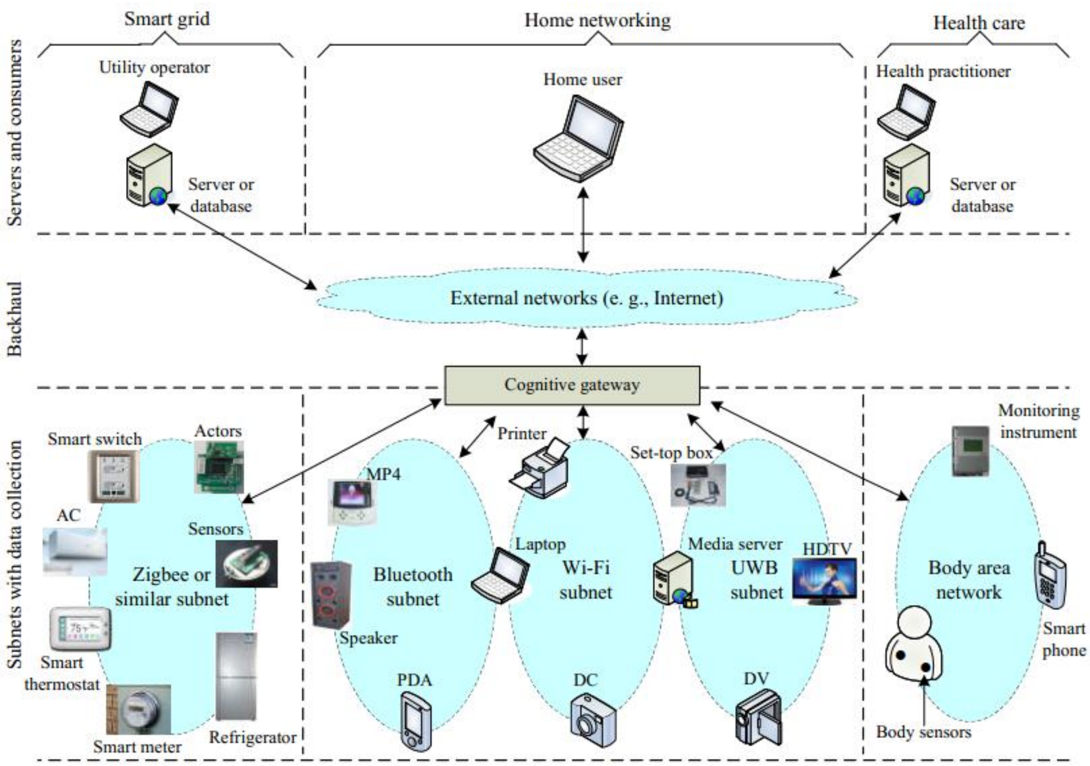

Fig. 3. M2M communications for smart grid, home networking, and health care

5.2.2 Health Care

Health care M2M networks are sub-networks within home networks. They are used to monitor people's health and inform those being monitored, as well as possibly their doctors, of any abnormal conditions that might occur. Data collectors in a health care network are body sensors to monitor various measures of good health, including blood pressure, temperature, heart rate, and cholesterol. Body sensors are connected to an on-person gateway, such as a smart phone, which also acts as the aggregator for all data collectors. Sensors send data to the smart phone which sends data over the Internet to health monitoring servers. Applications run on the servers that monitor the health of patients.

This M2M paradigm allows for the health of an entire population to be monitored in real time. Ambulances can be immediately dispatched to accident scenes and patients can be monitored at their homes just as effectively as in hospitals. For example, a patient's doctor can also immediately be informed if her patient suffers a heart attack. Moreover, health care M2M can help to track the progression of a virus outbreak by monitoring specific symptoms of the population. Patients that are suspected of being infected by the epidemic can be notified to seek medical care.

5.2.3 Smart Grid

On the basis of **Fig. 3**, the concrete smart grid communication architecture is further designed, as shown in **Fig. 4** [3]. Power is delivered from the power plant to end users through two components (i. e., the transmission substation located near the power plant, and a number of distribution substations). The considered smart grid communication topology is divided into a number of networks that feature real-life setups of a city or metropolitan area. Broadly speaking, a city has many neighborhoods. Each neighborhood has many buildings, and each building may have a number of apartments. The communication architecture is derived from this real-life planning of a metropolitan area.

Concretely, the communication architecture for the lower distribution network is divided into a number of hierarchical networks, namely, neighborhood area network (NAN), Building area network (BAN), and home area network (HAN). For simplicity, each distribution substation is considered to cover only one neighborhood zone. Each NAN may be composed of a number of BANs. On the other hand, every BAN contains a number of apartments. In **Fig. 4**, the apartments are shown to have their respective local area networks, each of which is referred to as a HAN. In addition, there are advanced meters called smart meters deployed in the smart grid architecture that represent advanced metering infrastructure to enable automated two-way communication between the utility meter and the utility provider. Smart meters are equipped with two interfaces, namely, power reading and communication gateway interfaces. The smart meters used in NANs, BANs, and HANs are referred to as NAN gateways, BAN gateways, and HAN gateways, respectively. In addition, based on the existing standards of smart grid, IP-based communications networking is preferred, which permits virtually effortless interconnections with HAN, BAN, and NAN.

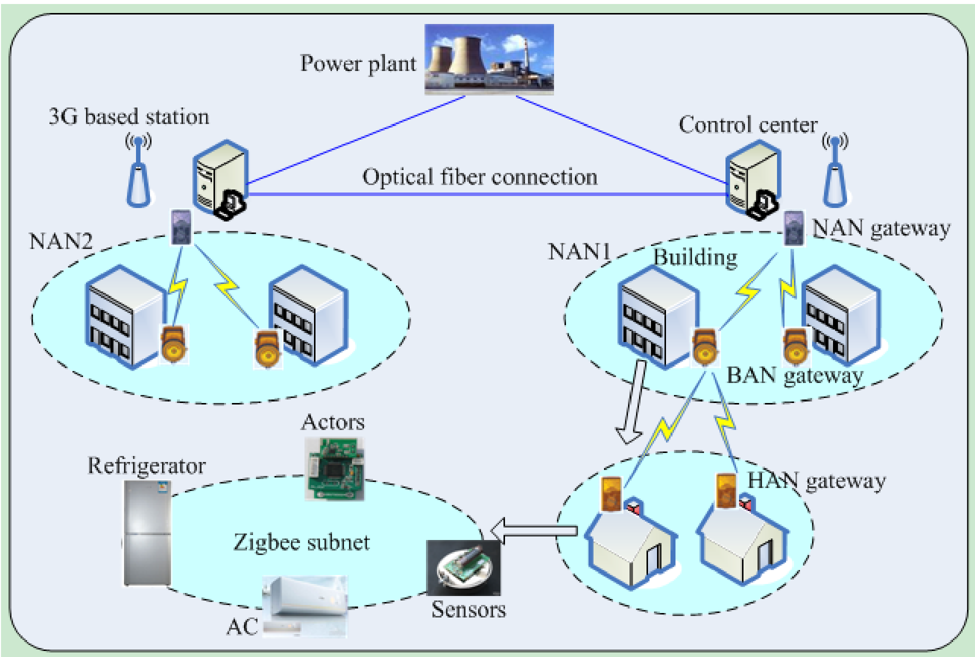

Fig. 4. Communication architecture of smart grid

6. Evolution of M2M Communications: CPS

Since the distributed real-time control, cloud computing, and advanced network techniques are further developed, the emerging CPS as an evolution of M2M, has been produced in M2M research. In this section, we propose an unmanned vehicle with WSNs navigation in the form of CPS, and analyze an example of CTS that takes a multi-disciplinary approach to combine cyber technologies, transportation engineering and human factors.

6.1 Unmanned Vehicle with WSNs Navigation

With the development of WSNs, M2M communications, and embedded systems, among others, some new solutions can be applied to unmanned vehicles. A program that integrates intelligent road and unmanned vehicle in the form of CPS is implemented, which essentially involves M2M technology [21]. **Fig. 5** shows a case of M2M communications in CPS, namely, the unmanned vehicle with WSNs navigation.

The platform architecture is mainly made up of WSNs, unmanned vehicle, and M2M communications. Many sensor nodes (e.g., IEEE 802.15.4/Zigbee) construct wireless networks with features of dynamic reorganization and reconfiguration. The unmanned vehicles with sensor nodes get datum from WSNs and further process information to determine the behavior of vehicles. An unmanned vehicle consists of a vision system, GPS, main body mainboard, and so on. The GPS and vision system serve as auxiliary location. The unmanned vehicles primarily realize navigation depending on WSNs. The unmanned vehicle without vision system locates and navigates through WSNs and GPS [22]. The open source Linux is chosen as operating system.

The navigation is realized by computing the locations of the beacon nodes and mobile node. Via WSNs navigation, the unmanned vehicle can 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 WSNs. This way, the use of dynamic programming achieves a rational trajectory. According to the current position of the unmanned vehicle, the wireless sensors for

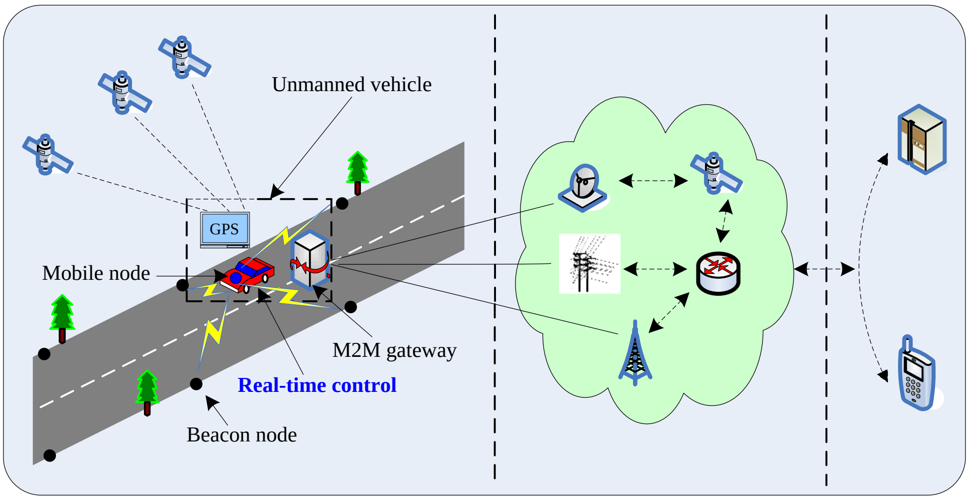

Fig. 5. Unmanned vehicle with WSNs navigation

communications continually switch. If a sensor goes wrong, this fault is solved by the recurring reorganization and reconfiguration of WSNs.

6.2 CTS

In recent years, vehicular ad-hoc network (VANET) using a moving car as node in a network to create a mobile network has become a reality. 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 and human factors, as shown in **Fig .6** [5][23]. The research aim of CTS is to improve road safety and efficiency using cyber technologies such as wireless technologies and distributed real-time control theroy.

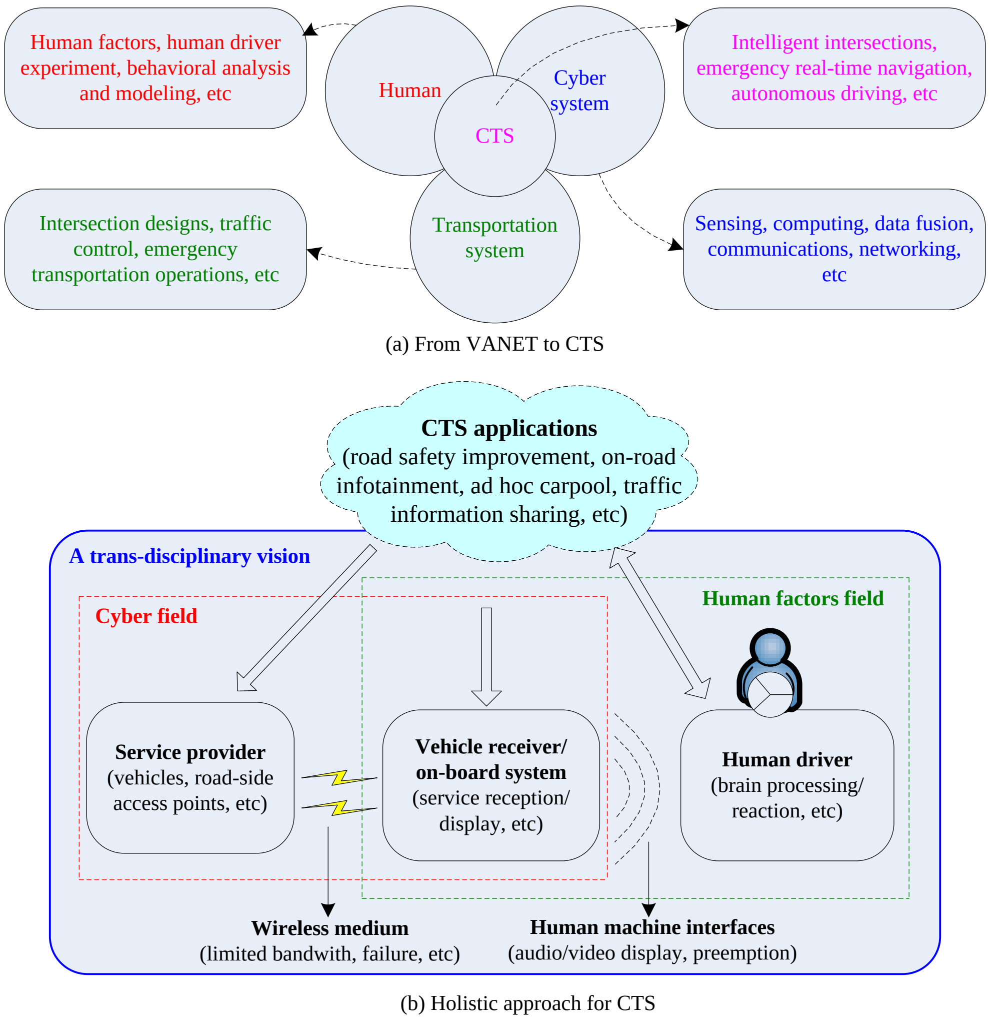

Fig. 6. CTS: An evolution of M2M communications

At present, the research for CTS focuses on the fwollowing two aspects [23]: 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. To improve traffic safety, we must develop and evaluate novel algorithms and protocols for prioritization, delivery and fusion of various warning messages so as to reduce drivers. 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, we need to develop a simulator that combines the main features of a traffic simulator, a networking simulator and a driving simulator. 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 technologies and theories such as WSNs, cloud computing, and distributed real-time control theroy gradually support the design requirements of CTS.

Fig. 7 shows an example of CTS applications for avoiding the intersection collision [5]. Once the intersection controller detects the approaching hazard vehicle, it immediately broadcasts an intersection violation warning (IVW). On the other road, the first vehicle that are crossing the intersection slams the brakes causing hard braking warnings (HBW). Meanwhile, the second vehicle also slams the brakes. From sensing to execution, the process must be finished in a short span of time. Therefore, the efficiency of this example particllarly depends on the real-time performance.

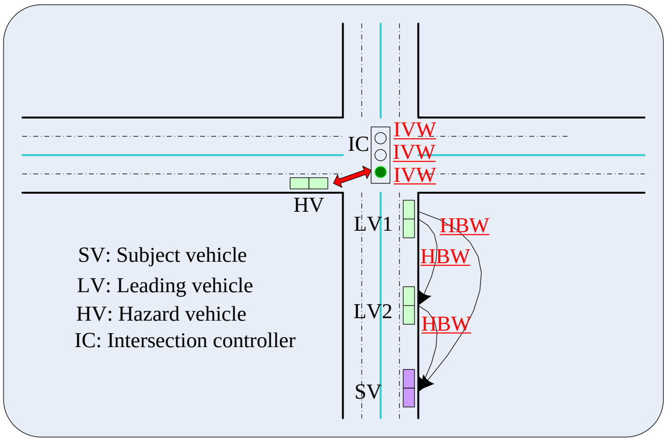

Fig. 7. An example of CTS applications

7. Challenges for Future Work

M2M is a very active new field, so the technology is beset with several significant challenges. A variety of questions need to be addressed. M2M communications will change some business processes by putting a greater amount of data in the hands of more people, thus requiring companies to train employees better. Futhermore, 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. In addition, 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. Currently, M2M applications generally use just the security provided by their networks.

During the design of capillary 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. The concrete challenges for cellular and capillary M2M communications are summarized in **Table 7** [15]. Moreover, as off-the-shelf hardware introducing some uncertainties are usually adopted, the optimization of cross-layer, cross- system, and cross-domain requires an innovative methodology.

For the proposed unmanned vehicle with WSNs navigation, the vehicle speed is intimately associated with system performance. As the speed increases, the real-time performance should meet the requirements. However, many factors, such as hardware platform and design methods, affect response speed. Furthermore, unmanned vehicles highlight high safety and reliability, which is more rigorous than other CPS. Therefore, an innovative methodology to guarantee system safety should be established. Currently, applications of unmanned vehicles with WSNs navigation are being conducted through miniature prototypes, and little work is focused on their practical implementations [24][25]. Analogously, the CTS applicatons (e. g., avoiding the intersection collision) also particularly rely on the real-time response.

Table 7. Challenges for M2M communications

Type	Challenges	Notes
Cellular M2M	Complexity and power	Modulation: simple to detect in downlink; constant envelope in uplink Processing: currently total over-kill; get it down by orders of magnitude
	Data rates	Uplink: allow for more uplink traffic without disturbing current traffic Downlink: mostly query; maybe embedded into the control plane
	Delays	Connection delay: end-to-end delays need to be improved by orders of magnitude Communication delay: generally solved for high rate only
	Architectural elements	Technical: handling many nodes, group management, and so on. Billing: who pays the bill and how; compete with LAN/WLAN /WSNs
Capillary M2M	Delays	Connection delay: optimize layer 2/layer 3 node discovery protocols Communication delay: ultra reliable and time-critical MAC urgently needed
	Security	Requirements: room for efficient end-to-end security solution Extras: fit security into standards, allow for aggregation, and so on
	Standards	So far: too many proprietary solutions in the market Need for: truly standardized embedded architecture
	Peer-to-Peer traffic	Traffic pattern: a lot more peer-to-peer traffic is emerging than initially thought Protocols: without jeopardizing converge-cast protocols, find solution

8. Conclusions

In the past few years, the emerging domain for M2M has been attracting significant interest, and will continue to do so for the years to come. M2M presents both challenges and opportunities to the industry. Although there are significant business and economic motivations for wireless operators and equipment manufacturers to invest in future generations of M2M services, the highly fragmented markets remain a hurdle, posing a risk to the forecasted growth of M2M markets.

In this article, we give a novel approach to illustrate the correlations among M2M, WSNs, CPS, and IoT. The existing research results regarding M2M architectures and standards development are reviewed. On this basis, some representative applications (e. g., home networking, health care, and smart grid) are used to show the bright prospects for M2M. In addition, a new solution applied to an unmanned vehicle is proposed, which integrates intelligent road with vehicle in the form of CPS. An example of CTS applications to avoid the intersection collision is also introduced. Several research issues and challenges are proposed, thus yielding more insights into this new field.

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