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A Cell Deployment Analysis Model for Multi-service Shared M2M Area Networks

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***Abstract*— In order to provide connectivity for various M2M devices in an easy and cost-effective manner, we propose the concept of "multi-service shared M2M area networks," which enables multiple M2M service providers to commonly use shared M2M gateways. The characteristics of M2M communications are analyzed in this paper based on various M2M use cases, and the technical challenges of shared M2M area networks are explained. Furthermore, we also propose a cell deployment analysis model suitable for shared M2M area networks, which can be applied for system design, especially from a cost-effectiveness viewpoint.**

Keywords—M2M, Network architecture, M2M area network, multi-service sharing, cost analysis, cell design

I. INTRODUCTION

The M2M/IoT (Machine-to-Machine/Internet of Things) era is imminent, in which "everything," including machines, will be connected to network clouds. Enormous numbers of M2M devices—ranging from 25 billion [1] to 50 billion [2]—are expected to be connected by 2020.

Several technical challenges will arise with M2M services that employ constrained devices such as sensors, since they have different characteristics from those of conventional "human" communication devices such as mobile phones. Several M2M devices have to operate for several years without recharging. In addition, setup configurations are often difficult because of their installation location and lack of human-friendly interfaces, and low cost operation is required. Such M2M devices are paid attention and referred to as massive M2M also in 5th generation (5G) mobile networks [3].

Applying M2M area network technologies is a promising approach to solve battery and cost problems, since we can use low-power radio protocols and share the same communication line of carrier network among lots of M2M devices. However, M2M gateways (M2M-GWs) are additionally necessary for accommodating M2M devices, which leads much complex setup configuration of M2M-GWs and devices.

In this paper, we propose a concept of multi-service shared M2M area networks, which support easy device installation and setup configuration with M2M platform (M2M-PF) assistance, and also offers further cost reduction by multi-service sharing of M2M area networks. We also discuss a cell deployment analysis model that we applied to verify the feasibility and effectiveness of the proposed concept.

This paper is organized as follows; in section II, we derive traffic characteristics of M2M communications and categorize their accommodation architectures. We introduce the concept of multi-service shared M2M area networks as well as deployment scenarios and challenges of the concept in Section III. In section IV, analysis models are proposed, and the results of verifying the feasibility are explained. Finally, we conclude the paper and note future work in section V.

II. CONVENTIONAL M2M ARCHITECTURE

A. Characteristics of M2M communications

Various M2M use cases have been discussed in many standardization organizations, consortia, or study projects. In order to derive M2M traffic characteristics, we surveyed and analyzed major M2M use cases of oneM2M [4], ETSI TC M2M [5], and FP7 [6]. our analysis, we derived three major characteristics of M2M communications, especially conventional M2M solution services, as follows:

1) Massive numbers of M2M devices

The number of smartphones and tablets has increased substantially. However, it will eventually reach a population ceiling because these devices are used in human communications. In contrast, the increase in the number of M2M devices is unlimited because they are deployed for sensing or actuating, and are not limited by the population. Thus, an explosive growth in M2M devices is expected.

2) Wide variety of M2M use cases

M2M use cases are very diverse. We found more than a hundred use cases in just a few studies [4]-[6], and they all have various characteristics. The variation in M2M use cases and communication characteristics are shown in Fig. 1, which shows the number of devices, mobility, and data volume for different use cases.

3) Severe cost constraints

Many M2M services are intended to streamline business operations by collecting or actuating something remotely. These services can reduce the number of workers working on-site and reduce the cost of these operations. At the very least, an M2M service should be provided at a cost that is lower than the labor cost being replaced by the M2M service. Moreover, the data volume of M2M devices tends to be small compared to that of intelligent devices such as smartphones or tablets. In view of the fact that the number of M2M devices is increasing exponentially, the M2M service cost for each M2M device should be much lower than that of conventional human communications such as mobile services.

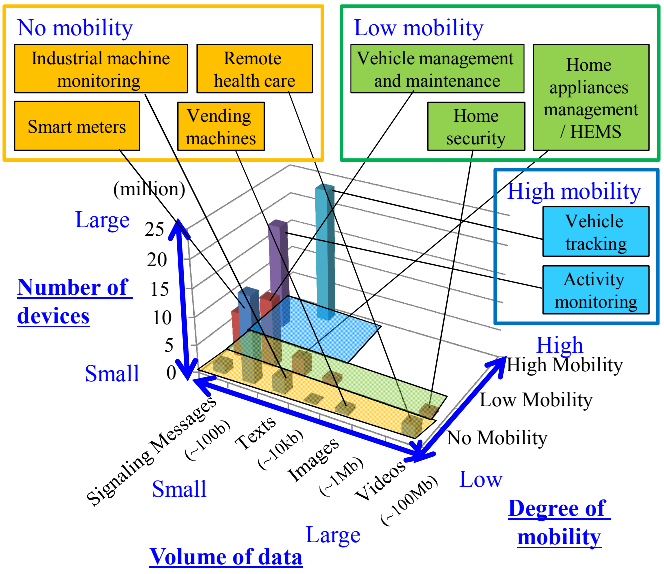


Fig. 1: M2M use case variation and communication characteristics.

Considering the above characteristics, we focus in particular on service applications such as sensor services in this paper. A huge number of devices are expected with such applications, but the amount of their traffic and their mobility are likely to be small. It is difficult to equip certain kinds of sensors with human interfaces such as displays or keyboards because of their cost and size limitations, and thus, the configurations to connect M2M devices to cloud applications are becoming more complex. Moreover, sometimes consumer appliances (e.g., refrigerators, washing machines) are installed by consumers themselves, who are not well experienced with IT (information technology). So, the M2M service should be connected automatically without consumers' complex expertise or operation.

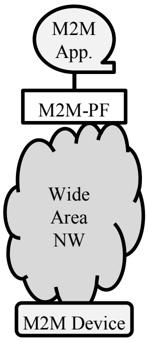
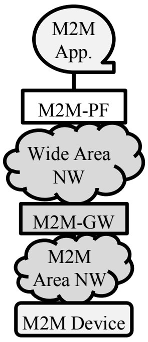
B. *M2M device accommodation architecture*

Conventional M2M solution services have two typical architectures used for device accommodation: direct and GW-based. These architectures are compared in Table I. With direct accommodation, devices are connected directly to mobile networks. In contrast, with the GW-based version, they are connected via M2M-GWs, which sometimes involve the use of more power-efficient M2M area network technology.

Direct accommodation provides wide area coverage and enables easy device management. The coverage of direct accommodation is the same as the area provided by the mobile network operators of the current mobile services. M2M service providers can install M2M devices anywhere they want without additional concern for coverage. Moreover, M2M devices can be easily activated / deactivated from a remote site with the Mobile Subscriber ISDN Number or remotely controlled using the Short Message Service.

However, the current mobile system is optimized for mobile devices such as smartphones, which requires wide coverage and broadband communications. It is not always suitable for M2M services, especially cost- or power- efficient use cases.

TABLE I: COMPARISON OF M2M DEVICE ACCOMMODATION ARCHITECTURES.

	Direct	GW-based
M2M Device accommodation structure		
Related technologies	3G/LTE	IEEE 802.15.4g/ZigBee/ Bluetooth/Wi-Fi/802.11ah
Area coverage	Wide area	Local area
Types of spectrum	Licensed spectrum	Unlicensed spectrum
Energy consumption	High	Low

In contrast, the GW-based architecture accommodates M2M devices located near the M2M-GW using rather shorter-range radio technologies such as Bluetooth [7], ZigBee [8], IEEE 802.15.4g [9], and IEEE 802.11ah [10], which utilize the unlicensed spectrum. The GW-based architecture can adopt low-power radio technologies and accommodate multiple M2M devices in one M2M-GW, which means that individual mobile subscription is not required for each M2M device.

In direct accommodation, standardization efforts are underway for LTE-M, the Long-Term Evolution system for M2M communication [11]. LTE-M is intended to optimize LTE for M2M communication and reduce power consumption. However, LTE-M still uses the licensed spectrum, and a license fee is charged for each device. In contrast, GW-based accommodation utilizes the unlicensed spectrum, and a license fee is not charged. Therefore, we have focused on GW-based accommodation, which can further reduce the expense of accommodating M2M devices.

C. *Challenges of GW-based architecture as a sole solution service*

While GW-based accommodation is a promising approach in terms of cost and power consumption, some challenges remain in providing area coverage and setup configuration of M2M devices. For conventional M2M solution services with GW-based architectures, M2M service providers have to deploy M2M-GWs where required, in addition to M2M application software, wide area network connectivity, and M2M device hardware.

Deploying a dedicated M2M area network for each M2M service solution costs much more, since it requires installation and configuration operation for M2M-GWs. Moreover, each M2M device needs to be configured individually to the paired M2M-GW, which makes it difficult for M2M service providers to start new M2M services.

III. MULTI-SERVICE SHARED M2M AREA NETWORKS

A. Concept of multi-service shared M2M area networks

In this section, we propose the concept of multi-service shared M2M area networks, which enables multiple M2M service providers to share the same M2M-GW and M2M-platform (M2M-PF) infrastructures. The concept of multi-service shared M2M area networks is shown in Fig. 2. M2M network platform functionalities such as identification (ID) management and device authentication/authorization are deployed in clouds over wide area networks. Under wide area networks, M2M-GWs that can be shared by multiple M2M service providers are deployed. In this concept, cooperation between an M2M-PF and M2M-GWs is important in providing network connectivity to each M2M device.

There are two key requirements in this concept. One is to reduce the time and cost of complex installations and setup configurations between M2M-GWs and M2M devices. The other is to reduce the connectivity costs of a wide area network by sharing its connectivity with multiple M2M services. These requirements can be met by aggregating M2M devices via the common M2M-GWs with multiple services and adding some M2M-PF functionalities such as ID/ authentication/authorization. This architecture can reduce the troublesome installation configuration expenses associated with M2M-GWs and M2M device installations and also enable service providers to maintain their devices from the network side remotely, and to flexibly apply low-power wireless technology. Therefore, this makes it easier for service starters to construct new M2M services and to promote cooperation between different M2M service providers.

B. Deployment scenario

As implied in the previous subsection, the problem of how and who to install M2M-GWs still exists with multi-service shared M2M area networks. Installing an M2M-GW is difficult and expensive, especially for small M2M service starters. The situation is the same for network operators, and they would have difficulty installing M2M-GWs nationwide due to the huge deployment costs.

In the early phase of deployment, multi-service shared M2M-GWs could be deployed for a large-scale, single solution. One candidate solution is smart metering. Smart meters are installed in individual homes where utility companies provide services. Therefore, M2M-GWs are placed so that they cover most living areas. Moreover, this solution is deployed on a gross scale, so the expenses of building M2M-GW infrastructures are likely to be acceptable.

After the deployment of multi-service shared M2M-GWs, other M2M service providers can start offering their M2M services. They could start the service without installing or managing their own M2M-GWs, and the provider of the smart metering service would benefit by sharing the subscription fee for the M2M-GW with other service providers.

C. Technical challenges of proposed concept

The functional architecture for the proposed system concept and its technical challenges are shown in Fig. 3. This architecture comprises M2M devices, multi-service shared common M2M-GWs that accommodate the various M2M devices, an M2M-PF, and M2M applications. There are four technical challenges with the proposed concept:

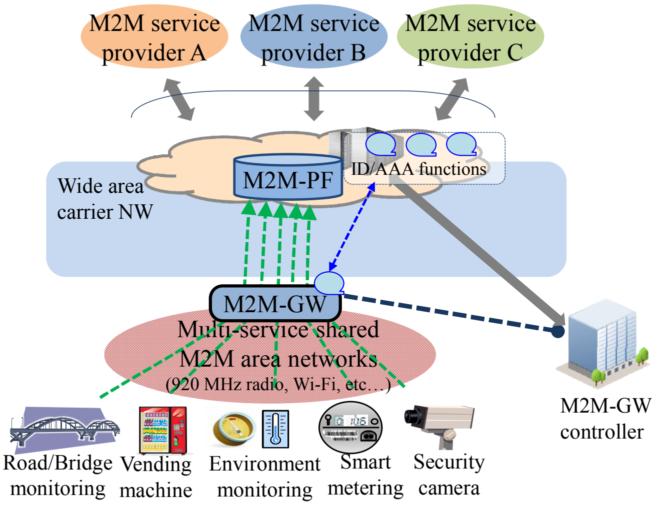


Fig. 2: Proposed concept of multi-service shared M2M area networks.

1) Mapping between M2M devices and M2M services

In order for multiple M2M services to share the same network, the proposed system needs to identify the corresponding M2M services for devices and correctly route packets between them, which is not required for the conventional solution that statically maps M2M devices and M2M services. Thus, some kind of ID cooperation technology would be required for dynamic ID operation.

2) Accommodation of different ID systems

The ID systems used for each application depends on the M2M services or applications because of their proprietary ID systems. Thus, we need to consider which ID systems are applied in the proposed system. The scheme of protocol conversion between different ID systems is another challenge.

3) Detection and rejection of unauthorized devices

Security in M2M/IoT is becoming an important issue because of M2M devices' low-authentication capabilities. In the proposed systems, a connectivity management scheme is necessary for detecting or rejecting unauthorized M2M devices.

4) Providing easy-to-use interface for service providers

Cooperation between M2M devices and M2M applications is necessary to provide M2M services. As an example, providing device management-related functionalities in the form of Web application programming interfaces (APIs) is one promising approach.

IV. ANALYSIS MODEL FOR PROPOSED SYSTEM

A. Proposed cell deployment analysis model

As mentioned in Section II, the affordable costs of M2M services concerns labor costs that can be reduced by M2M service automation or optimization. Here, we discuss the cell deployment model for multi-service shared M2M area networks.

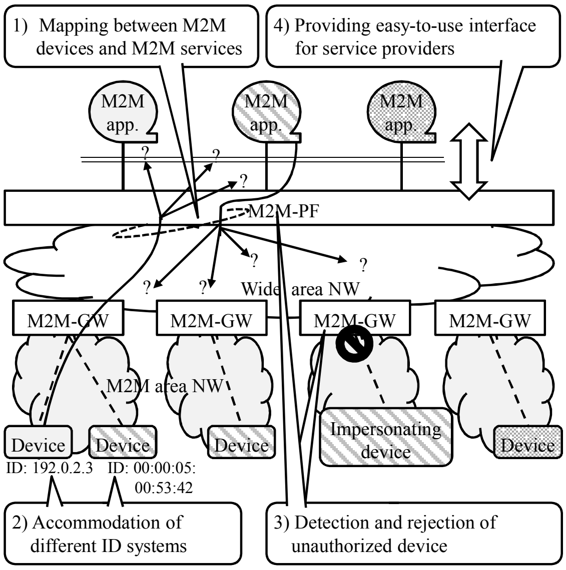


Fig. 3: Functional architecture of multi-service shared M2M area network and mapping of technical challenges.

When we implement M2M area networks as a single solution, we can easily decide cell design parameters such as the selection of radio technology, cell radius, and the number of devices within cells. However, in configurations involving multi-service sharing, it is not as easy to define these parameters individually. Access costs per device could also differ depending on the kind and number of target use cases. To avoid this difficulty, we focused on the device deployment density and applied a density coefficient normalized by human population density. In this manner, we propose a novel cell deployment analysis model that can be used for superposed multiple M2M use cases and devices considering access costs per device.

A cost structure model for GW-based M2M area networks is shown in Fig. 4. The capital expenditure (CAPEX) per period per communication line of a wide area network becomes $W+M/L$ where W is the fee per line of wide area network access per any period, M is the CAPEX of M2M-GWs, and L is the depreciation period. Then, the access cost ratio of the overall system cost is given by

$$E = (W + M/L) / (p \cdot K) \qquad (1)$$

where p is the number of M2M devices per M2M-GW and K is the sensing cost per M2M device, that is, the labor cost per device replaced by the M2M system. Here, the density coefficient of deployed M2M devices for each use case is given by

$$D_d(i) = c(i) \cdot D_p \qquad (2)$$

where D_p is the population density of the target areas. Note that $c(i)$ is a density coefficient of deployed M2M devices for use case i. Here, the density of M2M-GW is given by $D_g = 1/\pi R^2$, where R is the cell radius of the M2M area network. Thus, the number of M2M devices per M2M-GW is given by

$$\begin{aligned} p &= D_{d\cdot total} / D_g = c_{total} D_p / D_g \\ &= D_p \Sigma c(i) / D_g \end{aligned} \qquad (3)$$

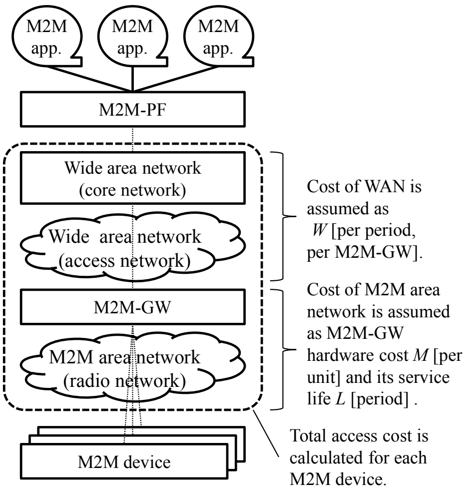


Fig. 4: Cost structure model for GW-based M2M area network system.

where $D_{d\cdot total}$ is the total number of M2M devices in the system, c_{total} is the density coefficient for the total deployed M2M devices, and $c_{total}=\Sigma c(i)$. Then, access cost ratio E can be derived from (1) - (3) as

$$E = (W + M/L) / (\pi R^2 \cdot D_p \cdot K \cdot \Sigma c(i)). \qquad (4)$$

In the actual situations, E becomes smaller than 1, since the area outside the section enclosed by a dashed line in Fig. 4 also requires additional costs, and the whole system incurs operating expenses, which includes functionality of M2M-PF or interface expenses of M2M devices. Here, this paper assumes that W is the monthly mobile subscription fee, K is the metering cost for utility use (equivalently, the metering labor cost per meter), M and L are assumed for set-top-box (STB) appliances in homes, and D_p is the population density.

B. Cell deployment design guidelines with proposed model

If we assume that the average number of people per household is two, the density coefficient for smart utility metering c_s can be assumed to be 0.5. If we assume that each person has five home network appliances on average, the density coefficient for home appliance traceability c_t can be assumed to be 5. In a similar manner, we can define different density coefficient figures for each different M2M service to be shared. Here, from the viewpoint of radio cell deployment design, the larger the cell radius R gets, the lower access cost ratio E we can achieve. The relationship between the density coefficient of deployed M2M devices c and access cost ratio E is shown in Fig. 5, with a cell radius of the M2M area network R=70, 100, 200[m] and population density D_p=1,000 [people/km^2]. In order to achieve E=0.2 as a tentative design target, a cell radius of 200[m] is required for the smart metering case (c_s=0.5), whereas only 70[m] is required for the home appliance traceability case (c_t=5). If we share both cases with the proposed shared M2M area networks (c_{total}=0.5+5=5.5), the required minimum cell radius of the M2M area network becomes smaller than 70[m], as shown in Fig. 5. In this manner, we can obtain useful guidelines on cell deployment design of M2M area networks and can easily assess the devices' accommodation design using the proposed analysis model.

Similarly, the relationship between density coefficient of deployed M2M devices c and the cell radius of M2M area network R is shown in Fig. 6, when access cost ratio E varies between 0.2 and 0.6. For example, if we set up the proposed system with c_{total}=5.5 with a tentative target of E=0.2, the required cell radius becomes 67[m]. As shown in this example, if we define both parameters of access cost ratio E and the cumulated density coefficient $c=c_{total}$, we can easily derive the minimum cell radius of the proposed system. In other words, this cell deployment analysis model can be used to choose the appropriate radio technology and device accommodation design considering multi-service sharing.

The relationship between density coefficient and cell radius to achieve E=0.2 with varying population density parameters (D_p = 343 ~ 4,000 [people/km^2]) is also shown in Fig. 7. Rural areas require a large cell radius for the system to meet the expense target over any value of c, whereas urban areas require a smaller radius with the same cost effectiveness. In this manner, the proposed model can easily factor in the area profiles considering differences in population density and can be used effectively for easy cell deployment design and assessment of M2M device accommodation.

V. CONCLUSION

In this paper, we derived characteristics of M2M communication traffic based on a wide range of use cases, and we studied accommodation architectures of conventional M2M solution services. Then, we proposed the concept of multi-service shared M2M area networks and explained its deployment scenarios and technical challenges, which focused on GW-based accommodation. In addition, we also proposed a cell deployment analysis model that provides useful guidelines on the cell design and assessment of the proposed system and effectively uses density parameters of M2M devices and translates target access cost into the cell radius of M2M area networks. Thus, this model can be used for choosing the appropriate radio technology and device accommodation design considering multi-service shared M2M area networks. As a future task, we will break down the technical challenges described in subsection III.C.

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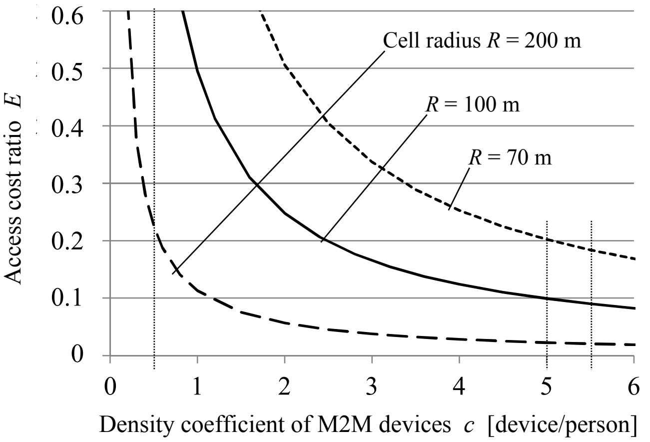

Fig. 5: Relationship between density coefficient c and access cost ratio E considering cell radius of M2M area networks.

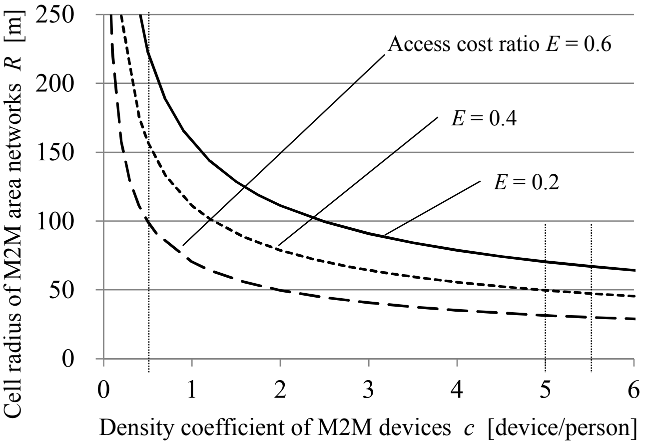

Fig. 6: Relationship between density coefficient c and cell radius R of M2M area networks.

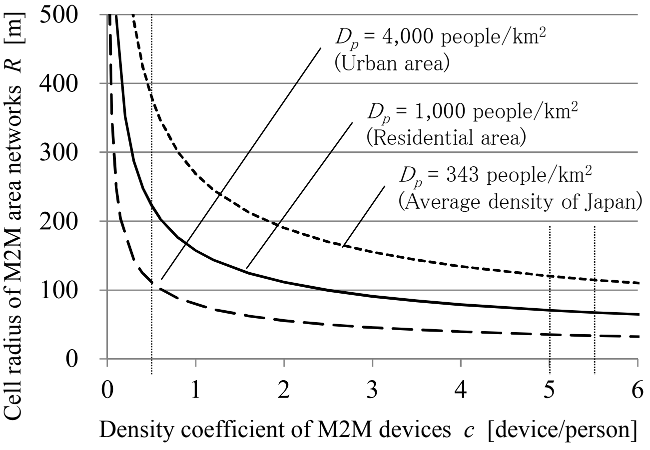

Fig. 7: Relationship between density coefficient c and cell radius of M2M area networks R to achieve E=0.2 considering population density.