This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JIOT.2017.2786349, IEEE Internet of Things Journal



# Edge Computing-based Intelligent Manhole Cover Management System for Smart Cities

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**Abstract-An intelligent manhole cover management system is one of the most important basic platforms in a smart city to prevent frequent manhole cover accidents. Manhole cover displacement, loss, and damage pose threats to personal safety, which is contrary to the aim of smart cities. This paper proposes an edge computing-based intelligent manhole cover management system (IMCS) for smart cities. A unique radio frequency identification tag with tilt and vibration sensors is used for each manhole cover, and a narrow-band internet of things is adopted for communication. Meanwhile, edge computing servers interact with corresponding management personnel through mobile devices based on the collected information. A demonstration application of the proposed IMCS in the Xiasha District of Hangzhou, China, showed its high efficiency. It efficiently reduced the average repair time, which could improve the security for both people and manhole covers.**

***Index Terms*—intelligent manhole cover, smart cities, RFID tag, NB-IoT, average repair time.**

## I. Introduction

SOME systems, such as drainage system, electric power system, network system, and so on, are laid underground in a modern city. In order to manage these systems, many holes with manhole covers are made in the pavement. However, manhole cover accidents, including vehicles and people falling in the holes, frequently occur as a result of manhole cover displacement, loss, and damage, threatening lives and safety. Obviously, this is contrary to the aim of smart cities.

Manhole cover accidents are primarily the result of uncovered holes, with no way to monitor their status in real time.

(1) The most common ways to obtain the status of manhole covers, especially their damage or loss, are periodic inspections by government officials and reports from people on the road, which depend on people. Periodic inspections by government officials consume large quantities of human resources to cover the large number of manhole covers in a city. Moreover, this does not provide real-time performance. It may take one or more days for problems to be found through such inspections, with even a month required in the suburbs. Such delays allow dangers to exist.

(2) It is difficult to solve the problem of manhole covers being stolen with no method for monitoring traditional manhole covers. Moreover, a manhole cover is easy to carry. Therefore, such thefts constitute not only public property losses, but also an increased risk of uncovered holes.

Both of these urgent problems are pushing to adoption of more intelligent technologies to manage all the manhole covers in a city, especially in a smart city. The intelligent manhole cover management system must have the following advantages:

(1) Self-perception. Every manhole cover has the ability to monitor whether it is tilted, damaged, or displaced, as well as the ability to locate itself.

(2) Active real-time alarm. Every manhole cover has the ability to actively alarm in real time when it has been tilted, damaged, or displaced.

(3) Real-time response. The intelligent manhole cover management system needs a mechanism to ensure a response to the alarm from a manhole cover in real time. Moreover, repair personnel can be scheduled in real time.

(4) Low management cost. One aim of the intelligent manhole cover management system is to reduce the costs, including those for human resources, bandwidth resources, and energy resources.

(5) Short average repair time. The most important aim is to shorten the average repair time for a tilted/damaged/displaced manhole cover to reduce the risk of falling into the hole.

In order to meet these requirements, this paper proposes an edge computing-based intelligent manhole cover management system (IMCS) for smart cities. Every manhole cover has a unique radio frequency identification (RFID) tag, as well as tilt and vibration sensors. Therefore, it can monitor itself. Because of the high efficiency of a narrow-band internet of things (NB-IoT), the IMCS adopts an NB-IoT for communication. Thus, all the manhole covers can communicate with a server. Moreover, an edge computing-based server is established to provide real-time responses. This server handles all the data for the manhole covers, including their locations and status values, in real time. Relevant persons communicate through the server, scheduling repair jobs, noticing abnormalities, and so on.

A demonstration application of the proposed IMCS in the

The work is supported by "the National Natural Science Foundation of China under Grant 61602137, No.61572172, No.61401107 and No.61602152" and supported by "Changzhou Sciences and Technology Program, No.CE20165023 and No.CE20160014" and "Six talent peaks project in Jiangsu Province, No.XYDXXJS-007" and "Maoming Engineering Research Center on Industrial Internet of Things (No. 517018)". Guangjie Han is the corresponding author.

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Xiasha District of Hangzhou, China, showed its high efficiency. The average response time, which was defined as the time between the manhole cover alarm and servers response, was less than 15 s. Moreover, the IMCS could reduce human resources by eliminating unnecessary periodic inspections.

The main contributions of this paper are as follows:

(1) Implementation of an edge computing-based IMCS, which can efficiently manage all the manhole covers in a city with greater safety and lower cost.

(2) An NB-IoT is adopted in our proposed IMCS for communication because it is meaningful to spread an NB-IoT in our internet of things (IoT) era.

(3) The demonstration application of the proposed IMCS showed its high efficiency.

The remainder of this paper is organized as follows. We first analyze the related work. Next, we illustrate the IMCS architecture. Subsequently, we discuss the demonstration application of the IMCS. We finally conclude this paper.

## II. RELATED WORK

RFID technology was proposed for communication between a reader and tags based on radio waves, making it possible to automatically track and locate or identify objects such as animals and people without the need for a line-of-sight method [1]. An RFID reader has two modes, fixed and static. RFID tags are intelligent barcodes, which allows them to be easily tracked. RFID tags communicate wirelessly with the reader. An RFID system can easily meet the self-perception requirement and provide a user with information about an objects type, location, and condition.

An RFID system has three main components: the RFID tags, RFID readers, and antenna. RFID tags are microprocessor chips, each of which consists of an integrated circuit with a memory. A unique code for identifying the tag is stored in the memory, which is called the tags ID. There are two types of tags: passive and active tags. The circuit sizes, communication distances, and power values are the mainly differences between them. Passive tags are smaller in size and cheaper, and the communication distance can be 8 m. However, active tags have their own power source for communication RFID technology has been identified as an attractive solution for intelligent objects [2]. RFID-based techniques have been used for monitoring displacement [3]. Therefore, in this study, we attached an RFID tag to each manhole cover to establish an intelligent management system [4].

The way we live is being revolutionized by the IoT. Everything and everyone can be connected in the IoT paradigm. More than 16 billion devices are currently connected worldwide. Ericsson forecast that there would be nearly 28 billion connections by 2021 [5]. Machine-to-machine (M2M) communication plays an essential role in the core of the IoT for connectivity [6]. The 3rd Generation Partnership Project (3GPP) introduced a new radio access network (RAN) technology call an NB-IoT [7], which can operate using a 200 kHz carrier. An NB-IoT is designed to have a low cost, long battery life, and high coverage, and can be used for the deployment of a large number of devices [8].

Additional benefits of an NB-IoT include low power consumption, less complexity in the transceiver design, coverage enhancement, and a lower cost for the radio chip. Discontinuous reception (DRX) can save power using a sleep mode, with periodic waking to send data. Moreover, more UEs can be supported by a single NB-IoT, even more than 100,000. Therefore, billions of connections can be supported by the NB-IoT, through adding additional carriers to the network. Manhole covers are part of a citys infrastructure, and can number into the millions. An NB-IoT is currently the best solution to support their connections.

Cloud computing has been the most dominant computing paradigm in the last decade. It involves the centralization of computing, storage, and network management in the cloud environment. One of the greatest advantages of cloud computing is the ability to deliver elastic computing power and storage, because of the vast resources of the clouds, which can satisfy the needs of resource-constrained end-user devices [9]. However, edge computing is becoming a new computing paradigm. It combines the IoT and cloud computing [10]. It processes data at the edge of the network, which has the potential to provide a better response time, battery life, bandwidth cost, data safety, and privacy [11].

In edge computing, the computing occurs in the proximity of the data sources. Therefore, it has some advantages compared to cloud computing [10, 12]. The results of some comparison have demonstrated these advantages [13-15]. In [16], the response times of a face recognition application were compared using cloud computing and edge computing. The result was clear, 169 ms for the edge computing was much better than the 900 ms for cloud computing. Similarly, in [17], the result also proved that edge computing could improve the response time, with values of 80 and 200 ms, when using cloudlets to offload computing tasks for wearable cognitive assistance. Moreover, the prototype proposed in [18], which combined partitioning and migration between mobile and cloud devices, could reduce the run time by more than 20 times [19, 20]. For the manhole cover management system, the response time is a key factor. A lower response time represents greater safety for people [21, 22]. Therefore, edge computing is one of the most important techniques in our IMCS.

## III. PROPOSED IMCS ARCHITECTURE

The IMCS mainly consists of three parts, as shown in Fig. 1. 1) An RFID tag with tilt and vibration sensors is attached to each manhole cover, which facilitates intelligent and active communication. 2) Both the internet and NB-IoT are adopted, with the NB-IoT used for efficient communication with manhole covers and the internet used for end user management. 3) An edge computing-based management system is established, which can store and make decision immediately. Moreover, managers can track all the manhole covers in real time.

### A. Manhole Cover Attached RFID Tag

Fig. 2 shows a manhole cover with the attached RFID tag to form the intelligent manhole cover, which has some merits:

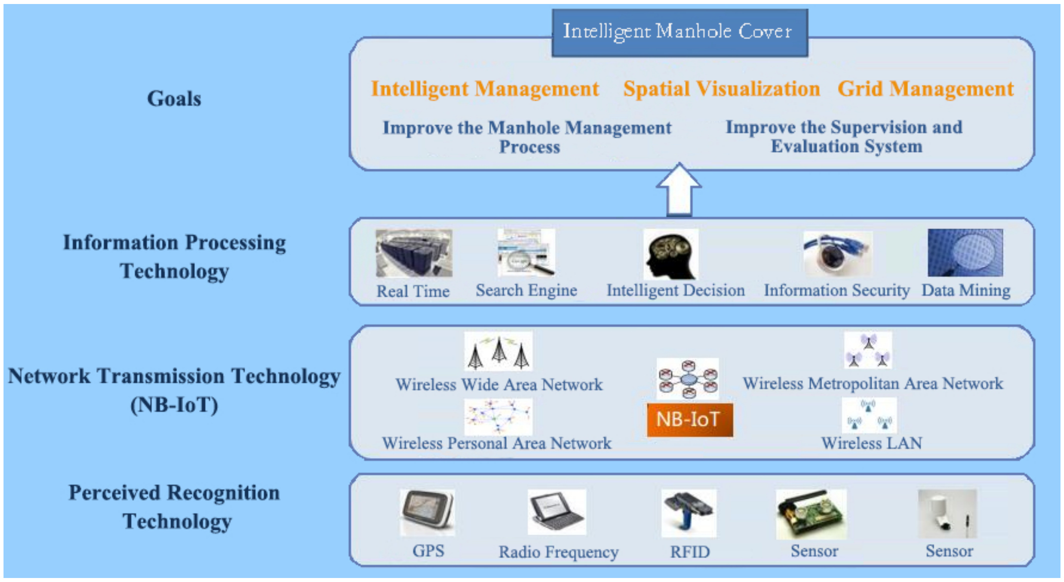


Fig. 1. IMCS architecture


Fig. 2. Manhole cover with attached RFID tag

(1) Some sensors are built into it, including tilt, vibration, and location sensors. Therefore, any movement, rotation, and vibration of the manhole cover can be immediately sensed. This is the most important part of the intelligent manhole cover.

(2) A 3.6 V lithium battery is built in for a power supply. It can work for 3-5 years.

(3) The NB-IoT communication module is built into it. All the manhole covers can communicate with the server through the NB-IoT. All the advantages of the NB-IoT can be merged into our IMCS, including its low power consumption, lower complexity in the transceiver design, enhanced coverage, and lower cost for the radio chip. The greatest advantage is the support for billions of connections to cover the large number of manhole covers in the city.

(4) An anti-demolition alarm can alarm immediately when then RFID tag is dismantled.

The RFID tag attached manhole cover has a self-perception ability, which allows it to report its own status. It has become an intelligent manhole cover.

In order to check whether all the manhole covers are on-line and working normally, a handheld machine is used, as shown in Fig. 3. This handheld machine is used to check all the manhole covers periodically. The period can be set in the IMCS. It can be set 5 s, 10 s, 15 s, and so on. The less of the period, the more overhead will be for the management system. Moreover, we have an aim in the response time for the IMCS, less than 15 s. Therefore, in this paper, we set 10 s. If some manhole covers are checked and found to have an off-line status, the server can locate them, and send relevant people to make repairs. There are various reasons for the manhole covers to be off-line. The power supply might have run out. The repair people only need to replace the batteries, and these manhole covers will be online again. Another reason might be problems with the network, which prevent the server from communicating with the manhole covers. Thus, the check will show an off-line result. Repairing the network will cause them to be back online.

### *B. Network with both NB-IoT and Internet*

The network is one of the most important parts for implementing the IMCS. The server needs to communicate with all the manhole covers. Managers must track all the manhole covers, and the server needs to schedule repair jobs with the relevant people. All of these operations are related to the network. However, different communication objects have different communication demands, as demonstrated in Fig. 4.

The main demand for the communication between the server and manhole covers is the large number of connections. There are millions of manhole covers in a city. Therefore, the network for this communication must support a large number. Moreover, in order to reduce human resources for manhole cover management, the intelligent manhole cover must operate

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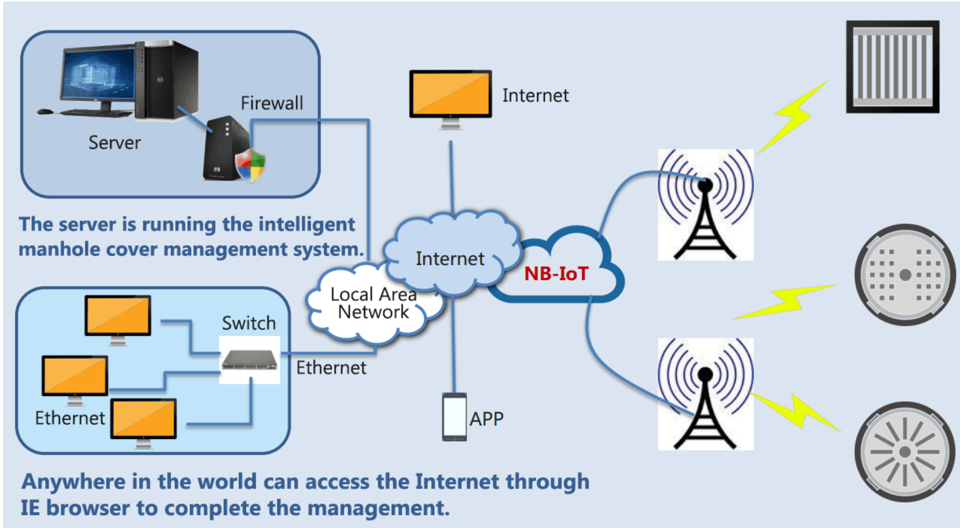


Fig. 4. Adopted network in IMCS

Fig. 3. Handheld device for checking manhole covers

without human intervention for as long as possible. Thus, the communication power must be low. In addition, the network must cover as large an area as possible because manhole covers are needed in every corner of the city. The currently proposed NB-IoT can meet these requirements. The NB-IoT is adopted in our IMCS to satisfy the communication needs between the server and all the manhole covers.

Both a local area network and the internet are adopted to allow managers to track the status of all the manhole covers in real time. In the management center, the management server and management terminal are connected by a local area network, and managers can immediately track the dynamic status of every manhole cover through the local area network. In order to track the dynamic status of each manhole cover immediately outside the management center, the internet is also adopted in the IMCS.

Both the internet and GPRS are adopted to allow the server to schedule repair jobs for the relevant people. The server can send repair jobs to the relevant people through the intelligent manhole cover management APP, and also by sending texts to mobile phones.

### C. Edge Computing based Management System

Based on the above two parts, the manhole cover with the attached RFID tag and the network that combines the NB-IoT and internet, the server can obtain the data from manhole covers. However, it is important to respond the abnormal condition immediately when receiving an alarm information from a manhole cover. For example, if a manhole cover is stolen by someone, the RFID tag with the sensors in the manhole cover makes it possible for the server to obtain dynamic information about its location, even if it is moving. Moreover, the management system must respond in real time to the dynamic location information, which can be used to find the stolen manhole cover and catch the thief. With a real-time response, things will become easier.

Cloud computing is designed to deliver elastic computing power and storage at a lower cost, which is a very successful business model. However, cloud computing cannot provide a real-time response. Edge computing can. Therefore, we established an edge computing-based IMCS. A server is used exclusively for running the management system to ensure real-time responses.

Some of the necessary parts for the proposed edge computing-based IMCS are listed below.

(1) Unique identification. Because of the large number of manhole covers in a city, the manhole covers need to be distinguished. Every manhole cover has a unique identification (ID). Moreover, it is very important to quickly locate an abnormal manhole cover, especially for repair. The location information (longitude, latitude) can solve this problem. Therefore, every manhole cover used has location information, (longitude, latitude).

(2) Manhole cover state. The most normal state for a manhole cover is simply online. However, some other states may appear, such as tilted, rotated, moved, and offline, when some abnormal event occurs to the manhole cover.

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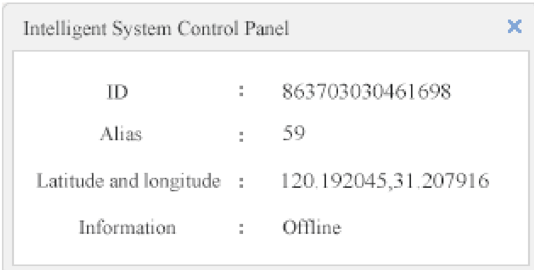


Fig. 6. Information for each manhole cover

(3) Display location in the map. All the manhole covers used in the city are shown on the city map for visualization. In addition, every manhole cover has its own information on the map, consisting of its state unique ID, and location (longitude, latitude). Different colors are used to easily distinguish the different states. This makes it easy to see the abnormal manhole covers. Moreover, the display must be real time. If one manhole cover tilts for some reason, the manhole cover on the map must immediately be set to the color of the tilted state. If a manhole cover is stolen, the manhole cover on the map should synchronously move according to the direction the actual manhole cover is moving.

(4) Texting relevant people using mobile phones. After the server receives an abnormal state, it will notify relevant people using mobile phones. The text that is sent will contain the following information: 1) the unique ID of the abnormal manhole cover, 2) its location (longitude, latitude), and 3) possible faults, which are used to accelerate the repair.

## IV. DEMONSTRATION APPLICATIONS

The proposed edge computing-based IMCS was applied in some districts of a city. We selected the Xiasha District of Hangzhou, China, for a demonstration application. In this district, 20 intelligent manhole covers were used. Every manhole cover in the system had five states: online and normal (represented only by being online on the map), tilted, rotated, moved, and offline (may be broken). Each state was identified by a different color to easily distinguish it. The color of each manhole cover was immediately changed when its state changed. Fig. 5 shows the main screen of the edge computing-based IMCS. All 20 intelligent manhole covers are online and normal in this figure.

The locations of the intelligent manhole covers shown in the figure are based on their real location data (longitude, latitude). The information of each manhole cover can immediately be seen, as shown as Fig. 6. The proposed IMCS can dynamically track the location on the map when the manhole cover is moved.

## V. EVALUATION OF RESULTS

In this section, we present the results of a case study where some abnormal states for the intelligent manhole covers were set to evaluate the effectiveness of the IMCS. First, we briefly introduce the system configuration of the server used for running the management system. Second, we analyze the response times for the abnormal states of the intelligent manhole covers. Third, we discuss the results of a reliability analysis for the IMCS, and finally, we propose extended applications based on the proposed IMCS.

TABLE I
SYSTEM CONFIGURATION.

| Attributes | configuration |
|---|---|
| Processor | Intel(R) Core(TM) i5-3470 3.20GHz |
| Memory | 4GB |
| OS | Windows 7 |
| Datebase | oracle |
| Disk | 1 TB |

### A. System Configuration

We established a server for the system in the management center. Table 1 lists the configuration specifications. For each manhole cover, we only stored dynamic information about its location (longitude, latitude) and state. Therefore, the amount of data was not very large, and a large storage system was not needed.

### B. Response Time Analysis

The greatest advantage of the edge computing-based IMCS is its quick response to abnormal states of the manhole covers to reduce risk. In order to analyze the response time of the IMCS, we recorded the time between the tilt/move/rotate actions for a manhole and the reception of a repair notice.

Fig. 7 shows the process of responding to an abnormal state. First, the manhole cover sends abnormal information to the base station through the NB-IoT according to the abnormal action. The sent information consists of the unique ID, location (longitude, latitude), and state. Second, after receiving the information from the manhole cover with the attached RFID tag, the base station sends the information to the sever through the internet. Third, the server sends the information to the relevant people to schedule a repair. Finally, the people go to the location of the abnormal manhole cover to make the repair. The received information consists of the location and state.

Because the time that passes before the maintenance personnel go to make the repair after receiving the scheduled job is not easy to evaluate, in this paper, we only use the first three parts to analyze the response time. The manhole cover sends abnormal information to the base station; the base station sends this abnormal information to the server; and the server sends the abnormal information to the relevant people.

Fig. 8 shows the average response times for different abnormal states. In this study, each abnormal state was tested 100 times with each manhole cover. The response time is the average of these 100 repetitions. The average response time for the tilted state is 9.4 s. This is the average of 20*100 tests, where every manhole cover was tilted 100 times. Similarly, the average response time for the rotated, moved, and offline states are 9.5 s, 9.4 s, and 13.6 s, respectively, which are also the averages of 20*100 tests.

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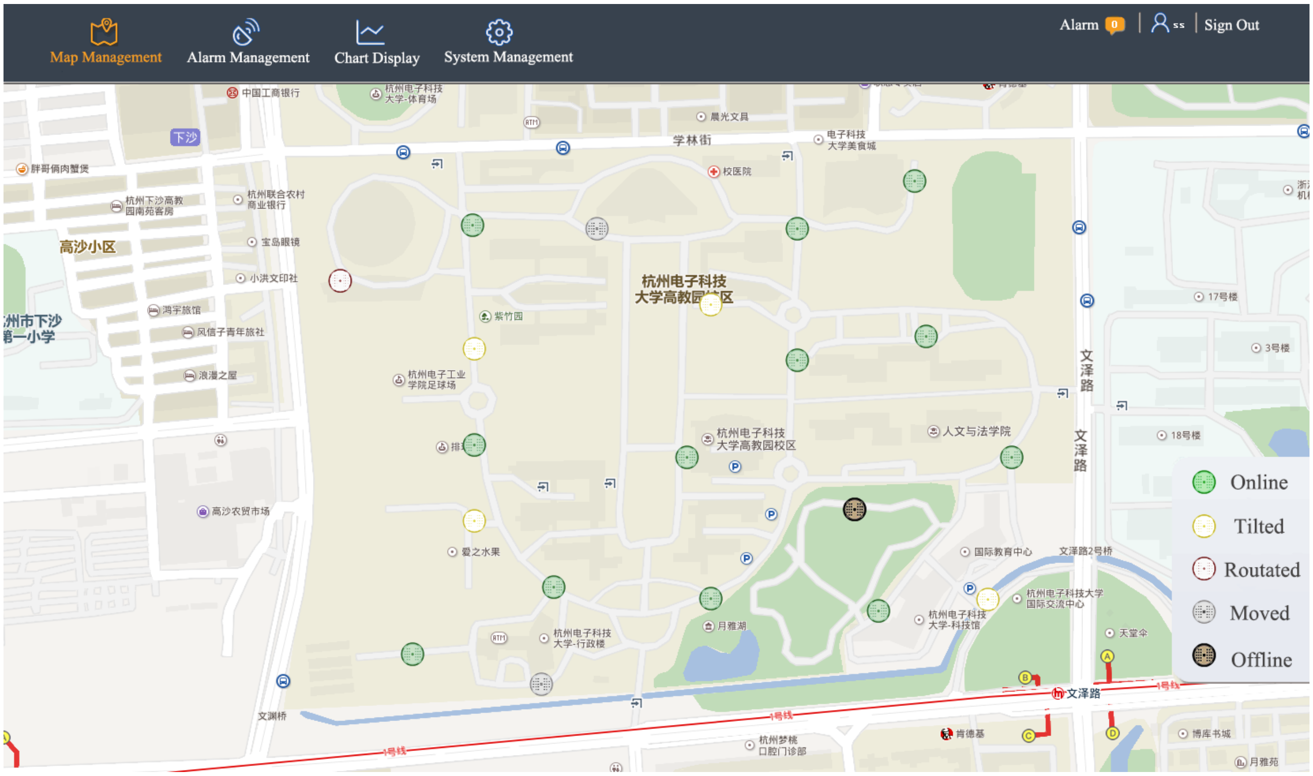


Fig. 5. Visualization on Baidu map of IMCS

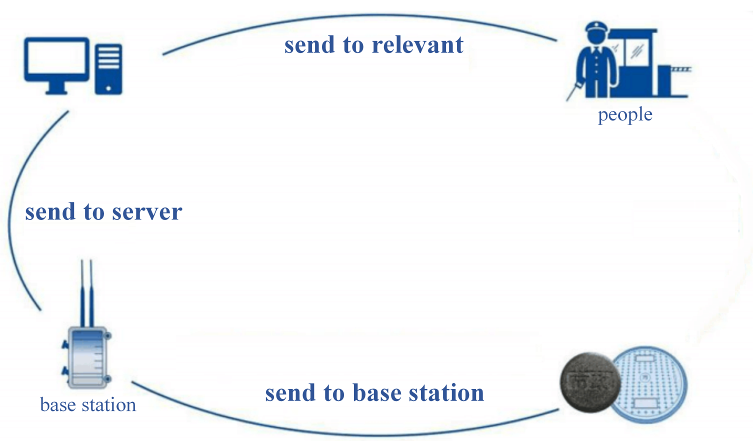


Fig. 7. Process of response

It is obviously that the average response time for the offline state is greater than those for the other abnormal states. This is mainly a result of the different mechanisms used for offline check and the tilted, rotated, and moved state checks. The tilted, rotated, and moved states are actively alarmed by the manhole cover itself, whereas the offline state is checked periodically by the running thread. The period was set to 10 s in this study. Therefore, the average response time was greater than those for the other states.

In any case, the response time of our proposed edge computing-based IMCS was less 15 s, which could reduce the risk to the lives of people.

In order to perform a detailed analysis of the time overhead of each communication part, we partitioned the response time into two parts. In one, the manhole cover sent abnormal information to the base station through the NB-IoT, and the base station sent the information to the server through internet, which is denoted as part 1 in the figure. In the other, the server sent the information to the relevant people, denoted by part 2 in the figure. Fig. 9 shows the average time overhead values of the two parts for the titled state. The average response time for the tilted state is 9.4 s, while the time overhead of part 1 is 5.1 s and the time overhead of part 2 is 4.3 s.

Fig. 10 and Fig. 11 show the average time overhead values of the two parts for the rotated and moved states, respectively. The average response time for the rotated state is 9.5 s, while the time overhead for part 1 is 5.2 s and the time overhead for part 2 is 4.3 s. Similarly, the average response time for the

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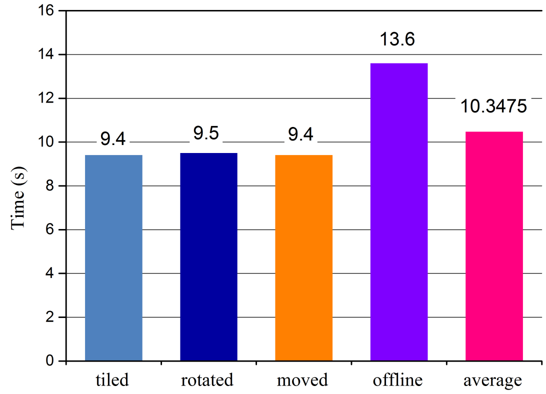


Fig. 8. Average response times for different abnormal states

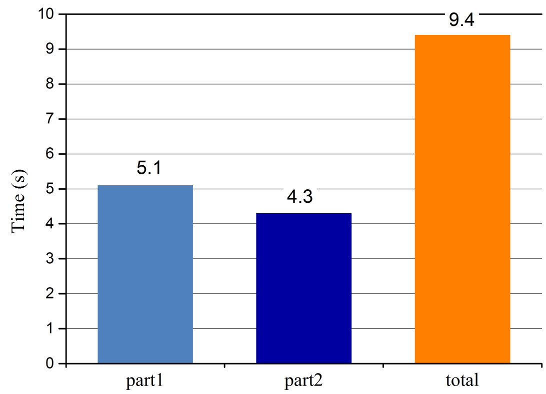


Fig. 9. Average time overhead values of two parts for tilted state

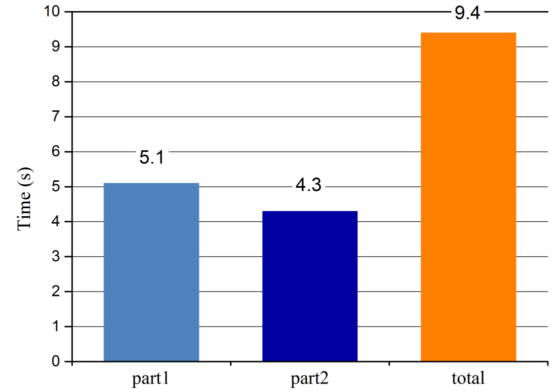


Fig. 11. Average time overhead values of two parts for moved state

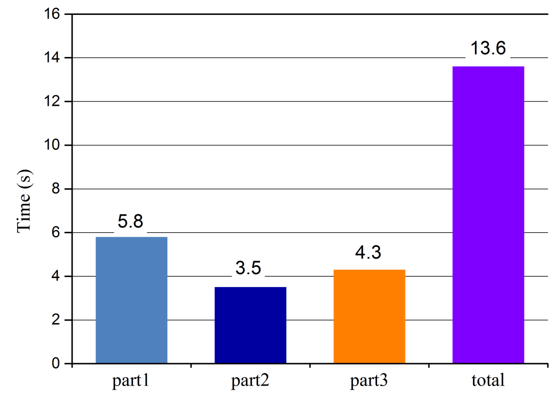


Fig. 12. Average time overhead values of three parts for offline state

moved state is 9.4 s, while the time overhead for part 1 is 5.1 s and the time overhead for part 2 is 4.3 s.

Based on Fig. 9, Fig. 10, and Fig. 11, it is obvious that the tilted, rotated, and moved states have similar actions. Moreover, the compositions of their response times are also similar.

However, the offline state is different from the above three states. The offline state cannot be alarmed by the manhole cover. It must be checked periodically by the thread in the management system. Therefore, the response time is partitioned into three parts. Part 1 is the time that the manhole cover is offline before being checked by the periodic thread. Part 2 is the time required by the check, and part 3 is the time needed by the server to send the information to the relevant people. Fig. 12 shows the three parts of the average time overhead for the offline state. The average response time for the offline state is 13.6 s, while the time overhead of part 1 is 5.8 s, the time overhead of part 2 is 3.5 s, and the time overhead of part 3 is 4.3 s. Compared to the above three abnormal state responses, the greater average response time for the offline state comes mainly from part 1, the periodic checking. Moreover, part 3 for the offline state is the same as part 2 for the above three states.

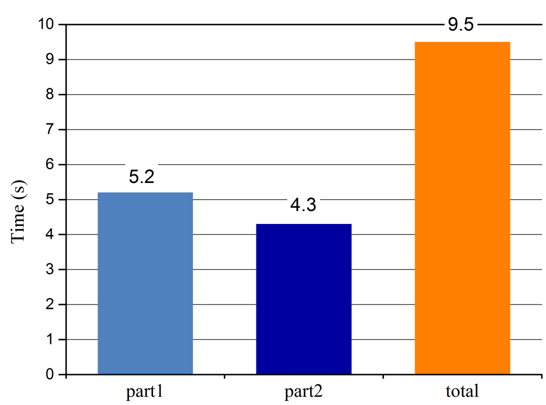


Fig. 10. Average time overhead values of two parts for rotated state

### C. Reliability Analysis

In this subsection, we mainly discuss the results of an analysis of the reliability of the proposed edge computing-based IMCS.

First, we use the percentage of time spent in the offline state as a reliability parameter. One reason is the fact that the offline state cannot be alarmed by the manhole cover, but can only be checked by the periodic thread of the management system. Another reason is the fact that the offline manhole cover is not intelligent; it does not have self-perception. Fig. 13 shows the percentage of time spent in the offline state compared to all the states. These data were collected over a period of 1

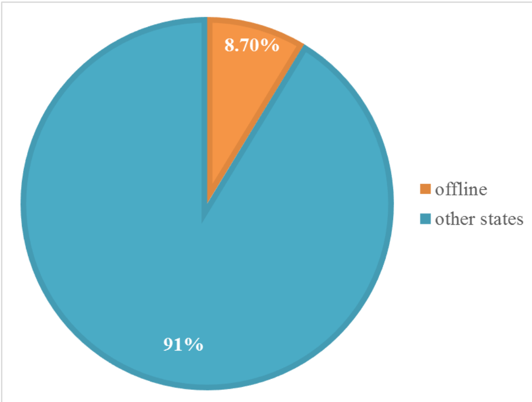


Fig. 13. Proportion of time in offline state compare to all states

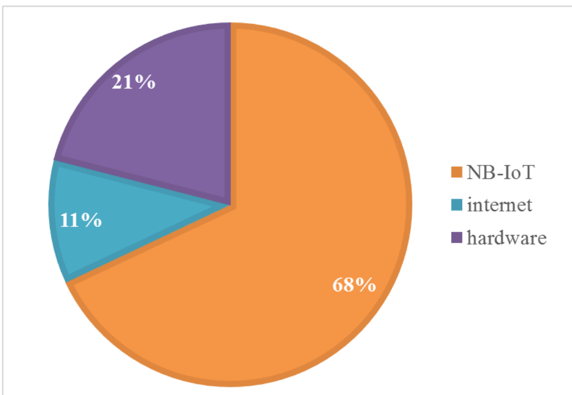


Fig. 14. Proportions of three reasons for offline state

month. The proportion of time spent in the offline state was almost 8.7%, which means 8.7% of the total time it could not be intelligently managed.

In order to determine why it was offline, we also analyze the offline state composition. There are various reasons why a manhole cover could be offline, including problems with the NB-IoT network, problems with the internet, and problems with the hardware in the manhole cover. In this paper, we mainly analyze these three reasons.

Fig. 14 shows the proportions of these three reasons for it to be in an offline state. In the figure, NB-IoT denotes problems with the NB-IoT network, internet denotes problems with the internet, and hardware denotes problems with the hardware in the manhole cover.

The proportion of the NB-IoT problem is 68%, which means 68% of the total offline time is caused by NB-IoT problems. The proportion of the internet problem is 11%, which means 11% of the total offline time is caused by internet problems. The proportion of the hardware problem is 21%, which means 21% of the total offline time is caused by hardware problems in the manhole cover.

Currently, the NB-IoT network is not stable enough and can be significantly improved. The hardware (consisting of both hardware and software) for the manhole cover can also be improved.

Second, we used the false rate as a reliability parameter. The

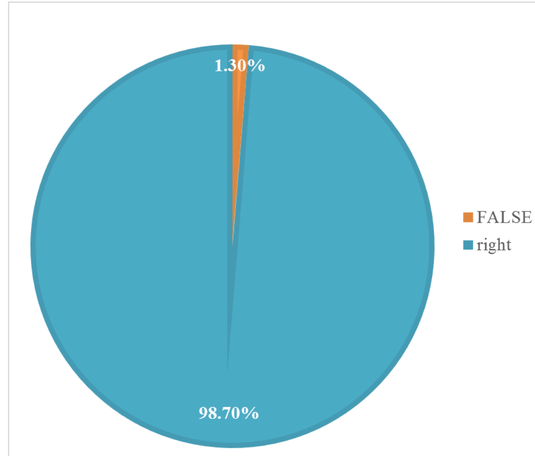


Fig. 15. False rate of IMCS

false rate denotes false information about the actions of the manhole cover. For example, the manhole cover is considered normal when no action is occurring, but tilted/rotated/moved information is sent to the server. Fig. 15 shows the false rate of the IMCS. It is obviously the false rate of the IMCS is low, only 1.3%, which almost can be ignored. In the figure, false denotes the false rate, and right indicates that the system is right.

### D. Extended Applications

There are some extended applications that can be merged into our proposed edge computing-based IMCS.

(1) Intelligent distribution. Multiple repair people are located in every corner of a city. When the server receives abnormal information from manhole covers, it is better for the intelligent management system to distribute the repair jobs based on the locations of both the repair people and the abnormal manhole covers. This can reduce the time and traffic burden.

(2) Optimal scheduling during floods. The manhole cover can be equipped with additional sensors such as for water level monitoring. In this way, during a flood, the system can be used for real-time evacuation mapping.

(3) Map. Every road in the city has numerous manhole covers. Therefore, more accurate traffic data could be collected using the manhole covers with attached sensors.

## VI. Conclusion

In order to cater to smart cities, this paper proposed an edge computing-based IMCS. A unique RFID tag with tilt and vibration sensors was attached to each manhole cover to make it more intelligent and allow it to monitor itself. The IMCS adopts an NB-IoT for communication because of its high efficiency. Thus, all the manhole covers can communicate with the server. Moreover, an edge computing-based server was established to satisfy the need for real-time responses. In this server, all the data, consisting of the locations and status values of all the manhole covers could be collected in real time. Relevant persons can be notified by the server to distribute repair jobs. A demonstration application of the proposed IMCS in the Xiasha District of Hangzhou, China, showed its high efficiency. The average response time, which denoted the time between the manhole cover alarm and server response, was less than 15 s. Moreover, the IMCS could reduce human resources by eliminating unnecessary periodic inspections.

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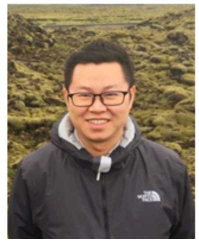

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