SSL: Smart Street Lamp based on Fog Computing for Smarter Cities

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Abstract—Both safety and energy conservation are very important advantages of smart cities. Namely, the city street lamp is correlated with both safety and energy conservation. Therefore, street lamp is an indispensable part of the smart cities. However, current street lamps have lack of smart characteristics, which increases both danger and energy consumption. In order to address these problems, a smart street lamp (SSL) based on fog computing for smarter cities is proposed in this paper. The advantages of the proposed SSL are: 1) fine management, because every street lamp can be operated independently; 2) dynamic brightness adjustment, all street lamps can be adjusted dynamically; 3) autonomous alarm on abnormal states, each street lamp can report the abnormal status independently, such as broken, stolen, and so on. The experimental results showed that proposed SSL can improve energy efficiency and reduce danger.

Index Terms—energy conservation, fog computing, safety, smart street lamp, smart cities.

I. INTRODUCTION

The main aim of the smart city relates to safer, more convenient, and more comfortable operation, and better energy conservation. Therefore, make an urban infrastructure be smarter is necessary for promoting the smart cities.

The street lamp as an essential part of urban infrastructure in the city, closely relates to the safety and energy conservation. Nowadays, it is impossible to imagine how the city would look like without street lamps. However, it is easy to predict that in that case the danger from traffic, robbery, and stealing would increase seriously. Moreover, it is necessary to optimize the current street lamp management because of its high energy consumption on daily basis.

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Presently, the street lamps mainly adopt manual management or light perception control, which both have certain disadvantages:

1) Long maintenance period. Both manual management and light perception control adopt manual patrol to check broken street lamps. Therefore, the maintenance period is too long, especially for the suburban street lamps, it can be even longer than few months. However, the danger increases just after the street lamps are broken, thus there could happen more traffic accidents, more robbery and stealing.

2) Hard fine grain control. It is obvious the manual management is not smart enough, and it can be difficulty controlled in real time. Moreover, in order to simplify manual management, one switch is used to control many street lamps simultaneously. For the light perception control, the flexibility is almost limited. Remote and real time controls are not part of current management systems.

3) High energy consumption. Current street lamps have only two states, off and on. Moreover, they cannot adjust their brightness. Therefore, they consume unnecessary energy. Sometimes, the street lamps can be dim to reduce energy consumption.

4) Easy stolen. There is no effective method to prevent stealing of street lamps. There are a large number of street lamps so it is particularly impossible to control all of them all the time. In order to avoid stealing, the effective way is to make street lamps have self-supervise ability.

In order to optimize the above-mentioned disadvantages to establish the smart cities, a new generation of street lamps has to improve lamp performance by introducing the following features:

1) Reduce maintenance period. Maintenance period is one of the most important parameters in smart cities. Therefore, the maintenance period must be reduced as much as possible. There must be a mechanism to check broken lamps in real time.

2) Satisfy fine grain control. Fine grain control includes few parts: first, every street lamp needs a unique identification to distinguish each other; second, every street lamp should be controlled independently; third, all street lamps should be controlled all the time; fourth, every street lamp has to be able to adjust its brightness according to current demands.

3) Decrease energy consumption. The brighter the street lamp lights up, the more energy is consumed. However, by using a dynamical light intensity adjustment according to current demands, energy consumption will decrease.

4) Autonomous alarm to avoid stealing. Every street lamp needs to have a self-protection ability. When it is stolen, it...
should autonomously send the alarm. In this way, the street lamp stealing can be avoided.

In this paper, we propose a smart street lamp (SSL) based on fog computing for smarter cities to meet the above four abilities. The proposed SSL consists of three main parts: an intelligent sensing street lamp, which can adjust lamp brightness, an autonomous alarm which reports about abnormal behavior; an efficient network, which is used for real-time communication between managers and massive street lamps; and lastly, a flexible management platform, which is easy and highly automated.

We verified the proposed SSL by its application in Xiasha District of Hangzhou, China, and very good results were obtained. The average maintenance period, which denotes the time period from the moment the street lamp is broken to the moment that is noticed by the server, is less than 20 minutes. Moreover, the proposed SSL can reduce human resources avoiding an inefficient manual patrol.

The main contributions of the proposed SSL are:

1) The hybrid network is adopted, the Narrow Band Internet of Things (NB-IoT) is used for real-time communication between server and massive street lamps, and the Internet is used for real-time communication between managers and server;

2) A flexible management platform is implemented, and it notifies the managers about broken street lamps at real time and automatically dispatches the maintenance staff to repair broken street lamps;

3) The states of all street lamps can be traced and adjusted in real time.

The remainder of this paper is organized as follows. In Section 2, the related works are analyzed. In Section 3, the SSL architecture is explained. Subsequently, the proposed SSL is verified by simulation as explained in Section 4, and obtained results are presented in Section 5. Lastly, a brief conclusion is given in Section 6.

II. RELATED WORKS

Some intelligent street lamps have been proposed based on many communication technologies, such as ZigBee [3], LPWA [6], GSM [5], and so on [22, 23], moreover, there are many other communication technologies, such as Bluetooth [2], UMTS/LTE [4], Wi-Fi [1], and so on. Each of these communication technologies has its own characteristic.

The Low-Power Wide-Area Network (LPWAN) or Low-Power Wide-Area (LPWA) is a type of wireless communications for wide-area networks. Therefore, the LPWA is designed to provide long-range communication with a low transmission rate of 0.3 kb/s up to 50 kb/s per channel. The LPWAN has the potential to revolutionize the Internet of Things by providing a reliable and low-cost solution for communication between embedded devices. LoRaWAN [20] is one of the most successful technologies in the LPWAN space. A LoRaWAN gateway, covering a range of tens of kilometers and able to serve up to thousands of end devices, must be carefully dimensioned to meet the requirements of each use case. Thus, the combination of the number of end devices, the selected SFs, and the number of channels will determine if the LoRaWAN ALOHA-based access and the maximum duty cycle regulation fit each use case. However, the deterministic monitoring and realtime operation cannot be guaranteed with the current LoRaWAN state of the art.

The Universal Mobile Telecommunications System (UMTS) is the third generation mobile cellular system based on the GSM standard. The UMTS is developed and maintained by the 3rd Generation Partnership Project (3GPP), and it is a component of the International Telecommunications Union IMT-2000 standard set. Moreover, both UMTS and CDMA2000 are the standard sets for networks based on the competing CDMA-One technology. The UMTS works at 2100 MHz (downlink - 2100 MHz, uplink - 1900 MHz) in Europe and most of Asia. Nowadays, it is also adopted in North America. The 2G (PCS) services work at 1900 MHz, and satellite communications work at 2100 MHz. The Regulators have freed up 2100-MHz range for 3G downlink, and some frequency ranges about 1700 MHz for its uplink. The characteristics of UMTS are high transmission rate and wide coverage. However, the characteristics of GSM are middle transmission rate and wide coverage.

On the other hand, Bluetooth is based on IEEE 802.15.1 standard, and ZigBee is based on IEEE 802.15.4 standard. These are two protocol standards for short-coverage wireless communications. For instance, Bluetooth is intended for a cordless mouse, keyboard, and hands-free headset, and ZigBee is designed for reliable wirelessly networked monitoring and control systems. The main characteristics of both Bluetooth and ZigBee are low transmission rate and short coverage.

The Wi-Fi (Wireless Fidelity) is commonly known as a wireless broadband or IEEE 802.11b standard. Moreover, Wi-Fi is defined as an industry standard for wireless network communications. The IEEE 802.11b standard is an extension of IEEE 802.11 standard, with working frequency of 2.4 GHz and transmission rate of up to 11 Mbps. The Wi-Fi is a technology which can enable wireless connection of terminals such as mobile phone, pad, personal computers, and so on. The Wi-Fi improves the interoperability between unlimited network products adopting the IEEE 802.1 standard. The main characteristics of Wi-Fi are high transmission rate and short coverage.

The characteristics of different wireless communication technologies [21] in terms of transmission rate and coverage are presented in Fig. 1.

In order to connect everything and everyone, the 3GPP introduced a new radio access network technology (RAN) called the Narrow Band Internet of Things (NB-IoT) [7], which operates with a carrier at 200 kHz. The NB-IoT is designed to have a low cost, long battery life, and high coverage, and can be used to connect a large number of devices [8]. Moreover, the NB-IoT is characterized by low power consumption, less complex transceiver, coverage enhancement, and low-cost radio chip [9-11]. The discontinuous reception (DRX) in NB-IoT can save power using a sleep mode based on periodic waking to send data. Moreover, numerous UEs can be supported by a single NB-IoT, even more than 100,000 UEs per NB-IoT channel. Therefore, billions of connections can be
supported by NB-IoT through adding the additional carriers to the network [12-15]. The superiorities of NB-IoT over the other wireless communication technologies are presented in Fig. 2.

Fig. 2: the characteristics of these different wireless communication technologies

III. SMART STREET LAMP (SSL)

The proposed smart street lamp (SSL) mainly consists of three parts: 1) intelligent sensing street lamp, the brightness of street lamp can be adjusted, and an autonomous alarm will notify about abnormal behavior; 2) efficient network, the network can be used for real time communication, the NB-IoT is adopted for communication between server and massive street lamps, and the Internet technology, such as Wi-Fi and 4G, are adopted for communication between server and managers; 3) flexible management platform, the management platform can optimize resource scheduling for easy and highly automated management. The SSL architecture is shown in Fig. 3.

A. Intelligent Sensing Street Lamp

The street lamp is equipped with some sensors, such as location sensor, infrared sensor, and light sensor, to form an intelligent sensing street lamp. Consequently, brightness of street lamps can be adjusted.

Using these sensors, the street lamp can communicate with the server through the network. In this paper, the street lamp periodically send reports on its current and voltage values. Based on the current and voltage values of the street lamp, the server can determine the street lamp state. If the current of the street lamp is zero, but the voltage is not zero, then the server can conclude that the light bulb may be broken.

By the location sensors in the street lamp, the server can be informed whether the street lamp is stolen. Moreover, the street lamp can be found when the street lamp is lost. Further, when the server finds the light bulbs of street lamps are broken, the server can send the detail location to the serviceman for repairing, so the serviceman can locate the broken street lamp accurately which improves efficiency.

The infrared sensor in street lamp makes the street lamp more intelligence. The street lamps can distinguish the demands for brightness. Namely, for street lamps in the unmanned area, the brightness should be turn down, and for the street lamps in the crowded area, the brightness needs to be turned up. Therefore, safety in the crowded areas can be guaranteed, and turning down of unmanned street lamps meets energy conservation requirement.

The light sensor in the street lamp makes the street lamp be sentient to the external environment.

Furthermore, the sensors makes the street lamp more intelligent. Consequently, street lamp can communicate with server and receive its commands. Namely, the server can send various commands, such as turn on, turn off, turn up, turn down, and check states, etc. When street lamps receive these commands they change their states according to the commands.

B. Efficient Network

Currently, there are various network technologies, such as LPWA, Bluetooth, ZigBee, UMTS/LTE, GSM, 4G, Wi-Fi, etc. However, the communication between street lamps and server has some limitations:
1) Since there are a large number of street lamps in the city, the communication network needs to satisfy the massive-communication demand.

2) The reliability must be high to meet the requirements of efficient management. Otherwise, the management system for street lamps will be useless.

3) It is better to ensure a wide coverage for the street lamps in the city.

4) The security must be at high level. It is intolerable that network is easy to break. If that happens, the city will be in danger.

5) The latency of street lamps is serious. It is important that street lamp changes its state in real time after manager sends the command.

6) The communication network should have low power consumption.

In order to satisfy the listed requirements, the proposed SSL adopts the NB-IoT due to its advantages of large coverage, high reliability, high security, low latency, low power consumption, and so on, which all helps to mitigate above-listed limitations.

However, there is a problem in NB-IoT communication between street lamps and server: the bandwidth of the NB-IoT is limited. The problem can be solved through time-shared when street lamps send messages to server. But it’s serious when server sends messages to street lamps. Therefore, a certain latency happen when massive commands are sent from the server to numerous street lamps simultaneously. In order to solve that latency, the big data analysis is employed in the SSL. The street lamps periodical send the data on external environment brightness to the server. Based on these data and big data analysis technology, it is easy to get the relationship between the external environment brightness and time and season for every street lamp. The relationship between the brightness of external environment and time and season for two street lamps at different locations is presented in Fig. 5. According to that relationship, the SSL can determine the priority for each street lamp. The darker the external environment is, the higher the priority will be. Further, the higher the priority of street lamp is, the sooner the command will be send.

C. Flexible Management Platform based on Fog Computing

Using both the intelligent sensing street lamps and efficient network, the server gets the information of all street lamps, consisting of lamp states, locations, external environment brightness, and so on. Therefore, the management platform is a key factor of the street lamp management system. Here, we implement a flexible management platform based on fog computing, which simplifies the management system [17, 18]. Moreover, the fog computing based server offers better real-time response, while cloud computing delivers the elastic computing power and storage at a lower cost [19].

As already mentioned, all street lamps periodically send information of their states to the server, and the server stores received information in the database. In order to find the abnormal states of street lamps, the server periodically checks the database. The check cycle can be set by managers. The longer the check cycle is, the longer the maintenance cycle of a broken street lamp is, and the lower the system cost is. Contrary, the shorter the check cycle is, the shorter the maintenance cycle of a broken street lamp is, and the higher the system cost is. 20 minute can be tolerable for both maintenance cycle and system cost. Therefore, to balance these two sides, we set the check cycle to 20 minutes, i.e. server checks states in database every 20 minutes.

The abnormal states are:

1) The street lamp bulb is broken. When server checks the street lamp and finds its current is equal to zero but its voltage differs from zero, it concludes the street lamp has a broken bulb.

2) The street lamp is offline. When server checks the street lamp and finds that no data are received from the lamp, it concludes the street lamp is in offline state.

3) The street lamp is in the power saving mode. When server checks the street lamp and finds both its current and voltage are lower than their normal values, it concludes the street lamp is in the power saving mode.

4) Fault. When server checks the street lamp and finds that both lamp current and voltage are equal to zero, and all street lamps in that region have the same state, the server concludes that a fault occurred, which may be caused by a power failure.

5) Close. When server checks the street lamp and finds that both lamp current and voltage are equal to zero, but not all street lamps in that region have the same state, the server concludes that the street lamp is closed.

The main operations in the check process are presented in Algorithm 1. The cost of Algorithm 1 is O(n), which n is the number of street lamps.

Moreover, after the server will check the abnormal states, the server will automatically send the information on abnormal lamp state consisting of street lamp ID, lamp location, and abnormal state description to the managers and nearest serviceman. Therefore, the maintenance period can be decreased seriously.

The managers can send commands using mobile application or Web browser. Therefore, the serviceman can receive the tasks through mobile application or SMS.

IV. SSL VERIFICATION

The graphical demonstration of SSL application in Xiasha is presented in Fig. 5. We arranged 10 movable street lamps in the district, of which each has 5 states: open, which denotes the street lamp is turned on with the highest brightness; save, which denotes the street lamp is turned down, close, which denotes the street lamp is turned off, offline, which denotes the street lamp cannot communicate with the server, and fault, which denotes the bulb is broken or power failure occurred. The offline and fault states are different, and distinguished through received data. For example, if received none data of one street lamp, then the street lamp is on the offline; else if received zero electric current and non-zero voltage of one street lamp, then the street lamp is on the fault.

In Fig. 5, different colors are used to demonstrate different states.
Fig. 4: The relationship between external environment brightness and time and season for two street lamps at different locations.

Fig. 5: Graphical demonstration of SSL application in Xiasha.

In Fig. 5, every street lamp contains the real-time information on its ID, location (longitude, latitude), and current state. This information can be immediately seen for each street lamp on the map in the format shown in Fig. 6. After the street lamp is moved, its location on the map changes simultaneously.

V. RESULTS EVALUATION

In this section, we evaluate the effectiveness of the proposed SSL by simulation of abnormal states of street lamps. Firstly, we introduce the system configuration based on fog computing server which implements flexible management platform. Secondly, we analyze the periodic maintenance of abnormal states of street lamps. Thirdly, we discuss the results of SSL reliability; and finally, we analyze the energy conservation.

Fig. 6: Real-time states for each street lamp.
Algorithm 1: shows the main operations for the check process.

Input:
- \texttt{current\_o}: the current value of open street lamp
- \texttt{voltage\_o}: the voltage value of open street lamp
- \texttt{current\_i}: the current value of being checked street lamp
- \texttt{voltage\_i}: the voltage value of being checked street lamp

Output:
- \texttt{S}: the state of the being checked street lamp

Begin
01: if current\_i = current\_o && voltage\_i = voltage\_o
02: \hspace{1em} S = open;
03: else if current\_i = 0 && voltage\_i != 0;
04: \hspace{1em} S = bulb is broken;
05: else if current\_i != 0 && voltage\_i = 0
06: \hspace{1em} S = save;
07: else if receive nothing from street lamp
08: \hspace{1em} S = offline;
09: else if current\_i = 0 && voltage\_i = 0
10: \hspace{1em} if all street lamps in this region have the same states
11: \hspace{1.5em} S = fault;
12: \hspace{1em} else
13: \hspace{2em} S = close;
14: \hspace{1em} else
15: \hspace{2em} return;
16: \hspace{1em} return;
End

**A. System Configuration**

We established the management platform with fog computing-based server. The system configurations are given in Table 1. For every street lamp, a dynamic information on its ID, location (longitude, latitude) and state is stored in server database.

<table>
<thead>
<tr>
<th>TABLE I: system configuration</th>
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<tbody>
<tr>
<td>Processor</td>
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<tr>
<td>Memory</td>
</tr>
<tr>
<td>OS</td>
</tr>
<tr>
<td>Database</td>
</tr>
<tr>
<td>Disk</td>
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</table>

**B. Analysis of Maintenance Period**

As already mentioned, safety is one of the most important characteristics of the smart cities, and periodic maintenance of street lamps is a key parameter for safety. The shorter the maintenance is, the better the safety will be. In this section, we analyze the maintenance of the proposed SSL.

In order to evaluate the average maintenance period of the SSL, the process from falling in the abnormal state to be repaired must be known. That process is presented in Fig. 7, wherein it can be seen that it consists of three parts:

1) The street lamp checks its own state, location, current and voltage, based on the data of its sensors. This self-state is periodically sent to the server through the NB-IoT network. In this paper, the sending period is set to 20 minutes. This part can be divided into two processes: each street lamp sends its states to the base station and base station sends states of all street lamps to the server.
2) After the server receives the data from street lamps, these data are immediately stored in the server database, and server starts the check process to find if there is any abnormal state in the database using the Algorithm 1. Similarly, the check period is also set to 20 minutes.
3) When server finds the abnormal state, it sends the information to the manager and nearest serviceman.

In this paper, we only consider the first two parts of the maintenance, because the time for the third part cannot be determined accurately. Moreover, the first two parts are the key parameters for evaluation of management platform.

In the simulation, the average maintenance period of SSL was 20 minutes based on the theoretical analysis. The first half of that period was spent on communication between street lamp and server, and the other half on periodic server check on abnormal states. Thus, the applied maintenance period was much shorter than in the traditional management systems.

The simulation results showed that 10 street lamps showed abnormal states for 100*10 times, which means that each street lamp had abnormal state for 100 times. During the simulation, we recorded the maintenance data, are the recorded data for the case of a broken bulb are presented in Fig. 8.

<table>
<thead>
<tr>
<th>Fig. 8: Distribution of maintenance periods for all street lamps</th>
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<tr>
<td><strong>A. Normal State</strong></td>
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<tr>
<td><strong>B. Broken Bulb</strong></td>
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<tr>
<td><strong>C. Fault State</strong></td>
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<tr>
<td><strong>D. Save State</strong></td>
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</tbody>
</table>

In Fig. 8, on x-axis, the L1-1 denotes the first report of the street Lamp 1, L10-100 denotes the 100th report of the street Lamp 10. On y-axis, the maintenance period is presented. The average maintenance period was 21.6 minutes, which is a little longer than 20 minutes, and which was mainly caused by insufficiently long simulation time. However, the obtained results verified the maintenance period was about 20 minutes.

Similarly, we conducted the simulation for offline state and fault state. The average maintenance period for offline state and fault state were 20.8 and 21.3 minutes, respectively. These maintenance periods were also about 20 minutes, which verifies good safety of the proposed SSL.

**C. Reliability Analysis**

However the proposed SSL has certain shortcomings. Namely, as presented in Fig. 9, the problem of the proposed SSL is that in some cases in the broken bulb condition, the server alarms the offline state. In Fig. 9, on x-axis, the L1-1 denotes the first report of the street Lamp 1, L10-100 denotes the 100th report of the street Lamp 10. The y-axis shows whether the state reported by the server is the same with the actual state of the street lamp, where 1 denotes the state reported by the server is the same as the actual state of the street lamp, and 2 denotes the state reported by the server differs from the actual state of the street lamp. In Fig. 9, 2 denotes the state of a broken bulb. Moreover, in 1000 checks, the actual state is not recognized only 3 times.

Similarly, Fig. 10 presents the results for 1000 server checks in the case of lamp fault state. As it is shown in Fig. 10, just in 5 cases the fault state is not recognized, in other 995 cases the actual state is recognized by the server.

In Fig. 11, the check results for the offline state are presented, and it can be seen that for the offline state the actual
Fig. 7: The process from falling in an abnormal state to be repaired.

Fig. 8: The maintenance period for the case of a broken bulb.

Fig. 9: The comparison of the actual lamp state with the state recognized by the server, where 1 denotes the state recognized by the server is the same as the actual state of the street lamp, and 2 denotes the state recognized by the server differs from the actual state of the street lamp, here 1 denotes the offline state and 2 denotes the broken bulb state.
Fig. 10: The comparison of the actual lamp state with the state recognized by the server, where 1 denotes the state recognized by the server is the same as the actual state of the street lamp, and 2 denotes the state recognized by the server differs from the actual state of the street lamp, here 1 denotes the offline state and 2 denotes the fault state.

Fig. 11: The comparison of the actual lamp state with the state recognized by the server, where 1 denotes the state recognized by the server is the same as the actual state of the street lamp, and here 1 denotes the offline state.

state is recognized in all 1000 reports, which means there is no error in state recognition.

The reason of above misrecognitions is mainly difference in judgement policy for abnormal states. Namely, if lamp current is equal to zero, but its voltage differs from zero, the street lamp state is defined as a broken bulb state; if both current and voltage are equal to zero, the street lamp state is defined as a fault state; but in the case that there are no received data from the street lamp the lamp state is defined as an offline state. In addition, if the network is currently unavailable, the server cannot receive data from the street lamp, so the server will define all these states as offline states.

Therefore, the reliability of the network, especially the NB-IoT, is a key factor for reliability of the proposed SSL. However, the NB-IoT cannot guarantee the network is one hundred percent reliable. Accordingly, although the inconsistencies may occur in the proposed SSL, their rate is very low.

VI. CONCLUSION

In order to satisfy the requirements of smart cities, this paper proposes a smart street lamp (SSL) based on fog computing. The SSL mainly consists of three parts: 1) intelligent sensing street lamp (street lamp brightness can be adjusted and autonomous alarm notifies about lamp abnormal state); 2) efficient network (real-time communication is achieved, the NB-IoT is adopted for communication between server and massive street lamps, and the Internet communication technology, such as Wi-Fi and 4G, is adopted for communication between server and managers); and 3) flexible management platform (management platform can optimize resource scheduling for easy and highly automated management of street lamp system).

The proposed SSL was verified by its application in Xiasha district of Hangzhou, China, and obtained results proved high efficiency. The average maintenance period, which denoted the time between the abnormal lamp state appeared and the server checked it, was about 20 minutes. Moreover, the proposed SSL can reduce human resources by eliminating unnecessary periodic inspections. In the future, we have two mainly works: 1) make the proposed SSL be used in current smart cities; 2) adopt the proposed technique to some other fields in smart city, such as parking, environmental monitoring, and so on.

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