International Journal of Advanced Smart Convergence Vol.8 No.2 218-226 (2019)
http://dx.doi.org/10.7236/IJASC.2019.8.2.218

IJASC 19-2-27

Information and Communication Technologies for Smart Water Grid Applications

Nobel Ballhysa[1], Gyewoon Choi[1] and Seongjoon Byeon[1*]

[1]*International Center for Urban Water Hydroinformatics Research and Innovation, Incheon, Korea*
[*]*Corresponding author: seongjoon.byeon@gmail.com*

Abstract

The use of Information and Communication Technologies (ICT) is the key to operate a change from the traditional manual reading of water meters and sensors to an automated system where high frequency data is remotely collected and analyzed in real time, one of the main components of a Smart Water Grid. The recent boom of ICT offers a wide range of both wired and wireless technologies to achieve this objective. We review and present in this article the most widely recognized technologies and protocols along with their respective advantages, drawbacks and applicability range which can be Home Area Network (HAN), Building Area Network (BAN) or Local/Neighborhood Area Network (LAN/NAN). We also present our findings and we give recommendations on the application of ICT in Smart Water Grids and future work needed.

Keywords: *Smart Water Management (SWM), Information and Communication Technologies (ICT), Automatic Meter Reading (AMR), Advanced Metering Infrastructure (AMI), Supervisory Control and Data Acquisition (SCADA).*

1. Introduction

Since we have entered the 21st century, new dangers and challenges have emerged as a consequence of both population growth and global warming [1]. Countries, especially those located in arid or semi-arid regions and less economically developed are facing serious threats of water scarcity resulting from various issues such as aging infrastructure, ICTs gap, lack of investment and institutional constraints or poor data [2]. Smart Water Management (SWM) has been defined by Kwater (South Korea's national water company) and the International Water Resources Association (IWRA) as "the use of Information and Communication Technology (ICT) to provide real-time, automated data for use in resolving water challenges through IWRM" [3]. A Smart Water Grid is the key structure for the application of SWM as an infrastructure which combines sensors, monitors, GIS, satellite mapping and other data sharing tools [3]. A Smart Water Grid system relies on meters and sensors as the fundamental devices for data acquisition but the data recorded by these devices needs to be collected. The traditional and current method for data collection consists in reading meters and sensors directly by sending employees on the field which is a tedious and time-consuming task and provides

Manuscript Received: June. 6, 2019 / Revised: June. 11, 2019 / Accepted: June. 16, 2019
Corresponding Author: seongjoon.byeon@gmail.com
Tel: +82-32-851-5731, Fax: +82-32-851-5730
International Center for Urban Water Hydroinformatics Research and Innovation, Incheon, Korea

low frequency data, incompatible with the concept of Smart Water Grid in which high frequency data should be gathered in a remote and automated way. In this document, we aim to review the available ICT which can be used to leverage the current data acquisition process, present their advantages, drawbacks and application range before summarizing our findings and giving recommendations.

2. ICT for Water Management

One of the characteristics of Smart Water Management is the ability to accurately predict consumption needs by analyzing usage patterns and one of the main tools category within SWM is "data acquisition and integration" [2]. Once data is efficiently gathered, water resources can then be combined in real time to answer to water demand. ICT can be used to shift from the traditional data acquisition process to a "smart" one and achieve the aforementioned targets. We have schematically represented in Figure 1 the three main concepts which are covered by the term "Smart Metering. Automatic Meter Reading (AMR) refers to an automatic transfer of data from a meter or sensor to a server (collection center) where the data is stored for further analysis. AMR only provides a one-way data transfer therefore it is sometimes excluded from the "Smart Metering" denomination. Advanced Metering Infrastructure (AMI) is a system similar to AMR except it creates a two-way data flow. Data-loggers store and send information with a higher density which also offers higher granularity of consumption data and enables real-time monitoring. Lastly, Supervisory Control and Data Acquisition (SCADA) is an architecture which uses information and communication technologies (ICT) to remotely control various types of devices. If the remotely controlled devices also provide data, then the same signal emission can also be used for data acquisition. The operational scale of these communication technologies is also very important as we can distinguish three of them, Home Area Network (HAN), Building Area Network (BAN) and Local/Neighborhood Area Network (LAN/NAN).

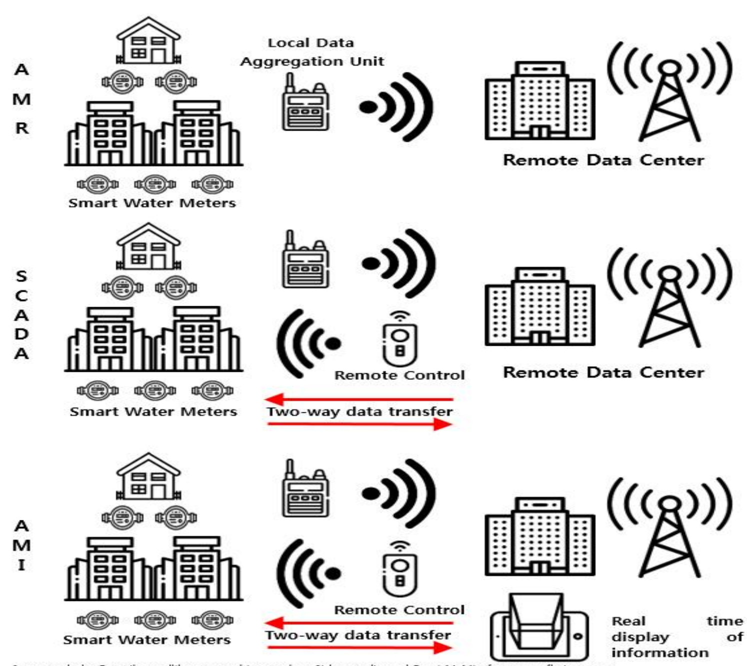

Figure 1. Three main concepts under the "Smart Metering" denomination

2.1 Wireless Local Area Network (WLAN)

Wireless Local Area Network (WLAN) provides robust and high-speed point to point and point to multi-point communication. It is based on the Institute of Electrical and Electronics Engineers IEEE 802.11 standard for LAN which covers 3 non-interoperable technologies: Frequency Hoping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) and Infrared (IR) [4]. Table 1 gives an overview of the main standards encompassed by the WLAN terminology. Low cost and easy installation have made the WLAN technology widely used around the world in both houses and commercial buildings which offer network access to their costumers [5] but some challenges are left to overcome:

- Reliability and availability of the signal which makes it suitable for non-critical end-point processes but water-providing companies may not rely on it for critical processes like billing [6].
- Electro-magnetic interference (EMI) and radio frequency interference (RFI) which can slow down the data transmission. This can either happen in high-voltage environments or due to other devices also working on radio frequencies [4].

Table 1. Standards encompassed in the WLAN technology

Standard (Commercial Name)	Data Rate	Frequency	Technique
IEEE 802.11a	54Mbps	5.8GHz	OFDM modulation
IEEE 802.11b (Wi-Fi)	11Mbps	2.4GHz	DSS modulation
IEEE 802.11g (Enhanced Wi-Fi)	54Mbps	2.4GHz	DSS modulation
IEEE 802.11i (WPA-2)	11Mbps	2.4GHz	AES (Advanced Encryption Standard)
IEEE 802.11n	Up to 600Mbps	2.4GHz and 5GHz	MIMO (Multiple Input Multiple Output)

2.2 Worldwide Interoperability for Microwave Access (WiMAX)

Worldwide Interoperability for Microwave Access (WiMAX) is a part of the IEEE 802.16 standard series firstly released in 2001 and was defined as a subset range with frequency bands of 2.3GHz, 2.5GHz and 3.5GHz licensed and assigned for mobile communication. For fixed communication, 3.5GHz and 5.8GHz frequency bands have been assigned but the 5.8GHz spectrum is not licensed [4]. The main advantages of using WiMAX reside in its high data rates and long distance coverage, making it suitable for revenue metering and to develop real-time pricing models based on real-time water consumption of users. It can also fasten the detection of power outage for measuring devices, thus increasing the reliability of the AMR structure. On the other hand, drawbacks are essentially a high hardware cost for the WiMAX tower which position needs to be carefully selected in order to optimize system efficiency while meeting requirements in terms of quality of service. Above a certain frequency (10GHz) penetration through obstacles becomes impossible, limiting WiMAX to being used at lower frequencies which present the disadvantage of being already licensed for most of them, inducing additional cost for broadband leasing [4].

2.3 ZigBee

ZigBee technology (introduced by the ZigBee alliance) is a wireless HAN technology based on IEEE 802.15.1 standard and encompassing few protocols for fast communication between small radio devices [6]. It comes with low power usage, data rate, complexity and cost of deployment as well as a covered distance of up to a few hundred meters which makes it suitable for AMR and home automation [7]. The technology works on frequencies of 868MHz, 915MHz and 2400MHz, unlicensed and using DSS modulation and offers a data rate of 20-250Kbps [4]. Application cases of ZigBee are numerous and many vendors are already integrating this technology in their smart water metering devices, technology which also presents the advantage of being robust. The main drawbacks reside in interference with other technologies using the same range of frequencies (such as WLAN), corruption of the 128-bit Advanced Encryption Standard (AES) encryption security system and a good applicability to American houses but less to the "mortar and brick" houses where signal penetration is more difficult [6].

2.4 Cellular

GSM/GPRS Global System for Mobile (GSM) is based on a standard developed by the European Telecommunications Standard Institute (ETSI) to describe the data transfer protocols of 2G cellular networks. By the middle 2000s this technology had achieved widespread coverage making it economically interesting to be used for Smart Water Grid applications as there is no additional installation cost. Moreover, smart meter vendors often integrate General Packet Radio Service (GPRS) modules in their devices [6] which can aggregate and communicate large amounts of data to servers. This technology is progressively being superseded by new generation cellular networks (3G, 4G and 5G) which offer higher data transmission rates and tackle some of the existing drawbacks (such as connectivity issues in houses basements).

3G/4G/5G The new generations of cellular technology include 3G (Code Division Multiple Access, CDMA), 4G (Long Term Evolution, LTE) and 5G (New Radio, NR) which operate on a frequency range of 824-894MHz and 1900MHz (3G), 700MHz to 2600MHz (4G) and 6GHz to 24GHz (5G). The data transmission rate varies from 60Kbps to 240Kbps (3G) to a maximum of 1Mbps for the 4G LTE-M standards (which are the standards dedicated to smart metering) making them suitable for point-to-point architecture and extensive data coverage. There are no maintenance costs and the recent growth in these technologies keeps quality of service and data rate improving very fast. The application of cellular data transmission in a Smart Water Grid perspective would mainly be providing communication between a local data logging unit and the remote data collection center or providing connection between a Remote Terminal Unit (RTU) and the SCADA server in the case of a SCADA architecture. The main drawbacks reside in expensive call costs and the fact that eventual dropouts can affect large data exchanges [4].

2.5 Bluetooth

Bluetooth (the tradename for Wireless Personal Area Network, WPAN) technology is based on the IEEE 802.15.1 standard and provides communication on an unlicensed frequency around 2.4GHz with a data-transmission rate from 721Kbps to 1Mbps. The operating range is limited (less than 100m) which makes this technology only suitable for HAN, in order to provide point-to-point or point-to-multipoint communication. The main drawbacks of Bluetooth are low security (the device switches to a discoverable mode to pair with another device and is then open to potential attack, [8]) and interference with technologies based on the IEEE 802.11 standard (WLAN) and the same frequency spectrum (2.4GHz, the same as ZigBee or Wi-Fi).

2.6 Power Line Communication (PLC)

Power Line Communication (PLC) is a technology which uses existing power lines for data transmission between metering devices and a data concentrator, which is then connected to the remote data center using wireless technologies such as cellular or WLAN/WiMAX [7]. PLC is therefore suitable for Neighborhood Area Networks (NAN). The latest versions of the PLC technology are based on Orthogonal Frequency Division Multiplexing (OFDM) and could theoretically achieve data transfer speeds up to 200Mbps [8]. In reality, achieved speeds depend widely on the configuration of the local power lines and typically, transmission over short ranges offers higher data rates [1] whereas the signal intensity proportionally decreases with the power circuit length, resulting in lower data rates and the eventual need for repeaters to transmit the signal over the entire grid [8]. The main advantages of PLC reside in its low cost due to the already existing infrastructure and robustness, the high voltage of power transmission lines making it also less vulnerable to attacks [8]. In addition to the already mentioned signal fading over long distances, the main drawback comes from interference with other communication signals due to the presence of higher harmonics in the power lines [5].

2.7 Digital Subscriber Line (DSL)

Digital Subscriber Lines (DSL) is a high speed data transmission technology which uses ADSL enabled telephone lines providing frequencies over 1MHz. It offers economic advantage as the infrastructure already exists. This usage however is restricted by downtime (which depends on how far away the customer is located from the serving telephone exchange, [7]) and low reliability [6].

2.8 Other Data Transmission Technologies

This chapter lists other data transmission technologies which are less widely recognized or used but still present interest to be incorporated into a Smart Water Grid system combined with above-listed main technologies.

Mobile Broadband Wireless Access (MBWA) The MBWA technology relies on the IEEE 802.20 standard also known as Mobile-Fi. This technology was essentially developed for allowing high mobility as it can provide high data-transmission rates (1~10Mbps) in licensed frequency bands below 3.5GHz with a stable signal for vehicles moving at speeds up to 250km/h, making it mostly suitable for plug-in electric vehicles (PEV). This technology is however not widespread therefore the infrastructure is lacking and costly [4].

Wireless Smart Utility Network (Wi-SUN) Wireless Smart Utility Network (Wi-SUN) refers to communication systems in which smart meters are equipped with Smart Utility Network (SUN) devices which can automatically relay the measured data to a local data collection unit [9]. The data is then sent to the remote data center using wide range ICT where it is treated and analyzed. Standardization work for Wi-SUN is performed by the Wi-SUN Alliance.

Wi-SUN communication systems operate mainly on 800-900MHz frequency bands and can be declined in 3 categories: a wide area open space communication with a coverage of 1km to 5km which can be used for data collection of smart meters from a fixed data collection unit, a wide area urban communication with a coverage of 100m to 2km which allows sensing and monitoring of buildings and stores which can also be operated from a smartphone thanks to the Wi-SUN router and finally a wide area mobile communication which allows collection of metering and sensing data from a moving vehicle (allowing speeds from 40km/h to 80km/h) with the same coverage of 100m to 2km. Data rates include 50Kbps, 100Kbps and 150Kbps [9].

Digital Microwave Digital Microwave technology is using a licensed 2.4GHz frequency and provides both high data transmission rate (155Mbps) and long range distance coverage (up to 60km). It is suitable for point-to-point communication but subject to signal fading and the necessity for encryption to ensure security results in enlarged messages and transmission latency [4].

Meter-Bus (M-BUS) Meter-Bus is a European standard (based on EN 13757-4) for remote reading of smart meters and sensors. The technology includes a “master” device connected to meters, sensors and actuators (which are named “slaves” in this scheme). M-BUS exists in a wired and wireless version, the latest which can operate in two modes:

- T mode: frequent transmission mode (several data transmissions per second or per minute) working at a frequency of 868MHz and offering data rates up to 100Kbps from the meters to the gateway.
- S mode: stationary mode (several data transmissions per day) which also operates at the frequency of 868MHz but offers data rates only up to 32.7Kbps.

For the wired version of M-BUS, each master-slave segment is limited to 250 devices (repeaters are then needed) and the master device can provide power to the slave devices during the installation process, few kilometers of distance can be thus covered. This technology can be used for the aggregation of data coming from various fixtures in a decentralized system [6].

Z-Wave Z-Wave is a low powered radio frequency technology which operates in the sub-1GHz frequency band (typically between 800MHz and 1GHz) and is based on the recommendation G.9959 from the International Telecommunications Union (ITU-T), specifications being defined by the Z-Wave Alliance. Applications typically consist in monitoring status and controlling several appliances at the HAN or BAN level with an operating range between 24m (indoor) and 90m (outdoor) and data rates up to 100Kbps. Security features include the AES 128bits encryption and the low frequency band prevents interference with other common HAN wireless technologies such as ZigBee and Bluetooth which operate on the 2.4GHz frequency band [10].

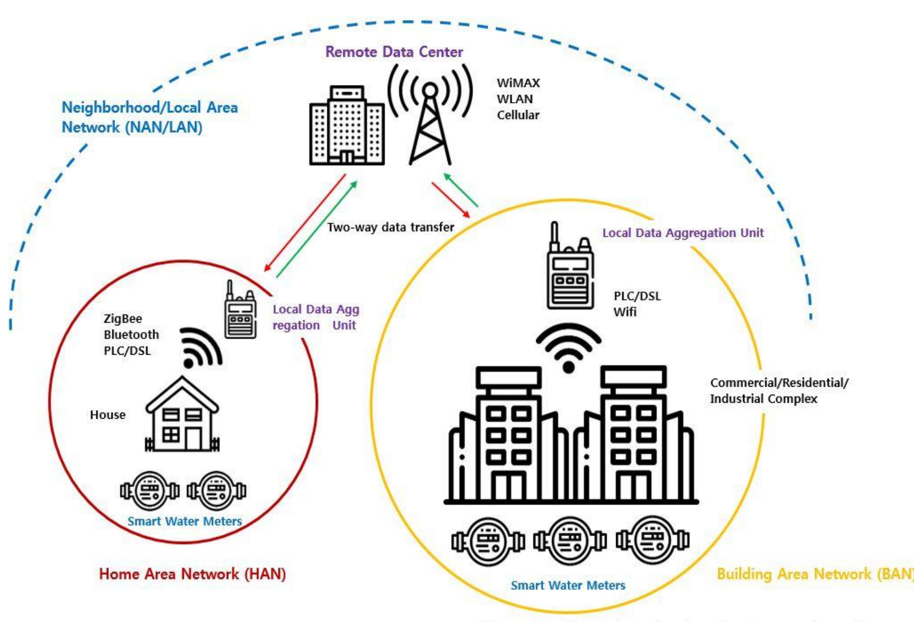

Figure 2. Schematic overview of data communication technologies and their range of application in Smart Water Grid systems

Table 2. Overview of Data Transmission Technologies and Application Range/Structure

Technology	Data Rate	Covered Distance	Application Range	Smart Metering Structure
WLAN	11Mbps ~ 600Mbps	Several dozens of kilometers	LAN	AMI
WiMAX	Up to 70Mbps	Up to 48km	LAN/NAN	AMR
Cellular	60~240Kbps (3G) Up to 1Mbps (4G)	Several dozens of kilometers	LAN/NAN	AMI/SCADA
PLC	Up to 200Mbps	Same as WLAN/WiMAX	BAN and HAN NAN (combined with WLAN/WiMAX)	AMR/SCADA
DSL	256Kbps to more than 100Mbps	Up to 2km	BAN and HAN	AMR/SCADA
ZigBee	200Kbps~250Kbps	A few hundred meters	HAN	AMR
Bluetooth	721Kbps~1Mbps	Less than 100m	HAN	AMR
MBWA	1Mbps~10Mbps	Less than 100m (mobile)	HAN	AMR (mobile vehicles)
Wi-SUN	50Kbps, 100Kbps, 150Kbps	From 100m to 5km	HAN/BAN LAN (combined with other wide range technologies)	AMR/AMI (+ mobile vehicles), SCADA
Digital Microwave	155Mbps	Up to 60km	LAN/NAN	AMR
M-BUS	32.7Kbps (S mode)/Up to 100Kbps (T mode)	Few kilometers	LAN/NAN	AMR
Z-Wave	40Kbps to 100Kbps	24m (indoor) to 90m (outdoor)	HAN	AMR/ SCADA

3. Discussions and findings

The recent development of ICT offers a wide range of options (Table 2) for data acquisition and integration when building a Smart Water Grid. In a tailored approach, consideration should firstly be given to the purpose of the infrastructure which can be remote reading of smart meters and sensors (AMR) but also additionally include remote control of smart units (SCADA) and real-time display of information to provide feedback to the customers (AMI). The second consideration is the granularity of data acquisition to be achieved and the use of data, from billing processes, pricing model setup to real-time location of pipe bursts and leaks, the technology offering appropriate data rate should be selected. Finally, the operating range of the architecture is very important. We have schematically represented in Figure 2 the three operating areas (BAN, HAN and NAN/LAN) and technologies applicable to each one of them. Communication technologies provide different coverage distances which makes them either appropriate for individual houses (HAN), commercial, industrial and residential complexes (BAN) or local neighborhoods and towns (LAN/NAN) with the potential to combine several technologies (for instance PLC associated with WLAN or WiMAX) to achieve desired purpose. Drawbacks should also be taken into account when designing a Smart Water Grid, essentially interference between technologies using similar frequency spectrums and conflicts between licensed and unlicensed broadband which may induce additional costs for leasing. A comprehensive and in-deep study should be carried out beforehand to identify needs precisely and avoid unanticipated issues which will prove costly to tackle after the infrastructure has already been set up. Interoperability is defined as the capacity for a user (or a service provider) to make several products and technologies work together without developing additional efforts (changes and adaptations), efforts which need to be reduced as they induce both delay and additional costs. Concepts such as Smart Water Grids and Smart Water Management (SWM) are very recent and until a few years ago the initiatives in this field were not interconnected and often led from a local viewpoint, focusing on specific conditions of the environments where the technologies would be applied. The need for standardization is then essential. In addition to the fact that standards benefit from broad recognition and can be seen as a "quality brand" on which both customers and service providers can rely on, standards are essentially needed because of the above-mentioned problem of interoperability. It is easily understandable that if a service provider for instance, is trying to integrate several meters and sensors into an AMR infrastructure, the efforts which will need to be deployed in order to achieve integration of all components will be reduced in case the service provider is working with well-known and compatible standards as opposed to making time-consuming and costly adjustments to try and adapt each unit technology to the bigger scheme. We can also add that vendors would also prefer to sell the same products everywhere around the world, based on broadly recognized standards instead of having to adapt to each local market which induces additional costs and, of course, reduces interoperability [11]. Smart Grids for electrical power supply have been developed earlier in comparison to Smart Grids for water supply therefore an important number of standards for ICT (which are shared by both grids) already exist and most of them have already been mentioned in this article. Several organizations are behind the standardization work on ICT used in Smart Grids such as the Institute of Electrical and Electronics Engineers (IEEE), the European Committee for Standardization, the American National Standards Institute (ANSI), the International Telecommunication Union (ITU) and others [5]. Work is still being carried out on key matters of data transmission such as range, amount, security or privacy. ITU for instance has established a Focus Group on SWM in June 2013 which brings together different stakeholders (research institutes, ICT organizations, industrial companies, municipalities, non-governmental organizations etc.) in order to identify new standardization work and gaps which need to be addressed. Work which is then carried out by the Study Group 5 (Environment and climate change) of the ITU Telecommunication Standardization Sector (ITU-T) [12]. It is very important to keep these initiatives active in order to develop always stronger standards and facilitate the deployment of Smart Grid infrastructures.

4. Conclusions

After we reviewed ICT available to be applied in a Smart Water Grid infrastructure, we can draw two main conclusions. Appropriate devices and architecture should be selected according to three criteria. Firstly, the purpose the structure is intended to achieve. Simple remote reading of meters and sensors, remote control of smart units (smart valves, smart pumps etc.) or two-way information flow (real-time information display to the customers) call for different devices and infrastructure. Secondly, the granularity of data which is needed. For example, a water body surveyed with sensors will need more frequent data sending if the conditions (temperature, water quality etc.) change very often and less frequent data sending if they stay similar through long periods of time. This impacts the choice of remote devices and transmission protocols as their capacity of storage and data-rates vary. Thirdly, the application range of the data collection infrastructure. Data coverage is very different from one data transmission technology to another. Infrastructure deployed at the level of a single house can use wired or wireless technologies with limited range (ZigBee, Bluetooth, Z-Wave etc.) whereas infrastructure deployed at the level of an entire town or city district will need the use of broad coverage technologies (WiMAX, W-LAN, Cellular etc.). Technologies with various ranges can be combined to achieve multi-scale data acquisition and monitoring. Furthermore, interoperability is one of the key challenges in order to ensure devices from various providers and companies work together seamlessly. Standardization is the key work which needs to be pushed forward, building always stronger standards which can be used and referred to as “quality labels” to facilitate the deployment of Smart Water Grids in the future. Therefore, we recommend that various stakeholders involved in the Smart Water Grid market should continue gathering under the umbrella of existing or new standardization organizations and carry out this work.

Acknowledgement

This research was supported by the National Strategic Project-Carbon Upcycling of the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (MSIT), the Ministry of Environment (ME) and the Ministry of Trade, Industry and Energy (MOTIE) (NRF-2017M3D8A2085273).

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