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FORUM

Barriers and Solutions to Smart Water Grid Development

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Abstract This limited review of smart water grid (SWG) development, challenges, and solutions provides an initial assessment of early attempts at operating SWGs. Though the cost and adoption issues are critical, potential benefits of SWGs such as efficient water conservation and distribution sustain the development of SWGs around the world. The review finds that the keys to success are the new regulations concerning data access and ownership to solve problems of security and privacy; consumer literacy to accept and use SWGs; active private sector involvement to coordinate SWG development; government-funded pilot projects and trial centers; and integration with sustainable water management.

Keywords Smart water grid · Privacy · Efficiency · Conservation

Introduction

Residential, commercial, or industrial facilities typically use a single flow meter to measure total water usage. The breakdown of water consumption for different uses is not generally available. Therefore, leaks are difficult to detect by metering, and users lack information on potential inefficiencies regarding water usage. One option is to install additional meters within a facility. With the current technology, installing meters for every fixture would be prohibitively expensive for most end users (Froehlich et al. 2009).

An alternative to installing additional flow meters is to use a device that measures pressure waves. Each fixture in a water system generates a pressure "signature" that propagates throughout the piping system and can be detected using sensitive pressure gauges that identify each signature. One such technology called HydroSense can identify each signature in a single family home (e.g., dishwashers, faucets, toilets) using only one sensor (Froehlich et al. 2009). If a leak occurs in the system, the sensing device will detect the leak as "noise" in the system. In addition, smart valves and pumps associated with metering can adjust their operations based on signals from sensors as well as environmental conditions. Adjustments in the system can be automated or remotely adjusted manually (Brzozowski 2010).

Such water management activities using information technology are part of the new trend termed as smart water grid (SWG). It is an effort to use the automated metering, sensor networks, and demand response applications to integrate water management (Boulos and Wiley 2013; Hinchman et al. 2012). It is a combination of information technology (smart), water management, and infrastructure (grid) to conserve water efficiently and deliver real-time data to users (Byeon et al. 2015). It includes smart water meters for measuring flow and pressure as well as sensors to detect leaks and contamination (Brzozowski 2013; Ruggaber et al. 2007; Maier et al. 2009; Vaseashta 2011; Mistry 2011). The benefits include better informed usage patterns of the community, the provision of evidence for education and policy changes, long-term water conservation practices, and collaborative community development of water saving initiatives (Giurco et al. 2010).

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Though some literature exists on SWG development, few academic reviews are available to document the extent of the SWG development. The objective of this review is to examine the current status of SWG development and discuss barriers and solutions to its development. This review not only informs SWG developers of the worldwide trend but also provides ways to promote its development in conjunction with sustainable water management.

Status of AMI Development

Depending on the country, SWG demonstrates varying sets of components. The Automated metering infrastructure (AMI) is the most developed form of the SWG (Choi et al. 2013). AMI is a point to multi-point network using a licensed spectrum to establish individual communication between a data collector and several endpoints. Smart meters installed in homes communicate as the endpoints in this infrastructure, whereby real-time data relevant to grid-connected water consumption are relayed between each endpoint and a centralized data collector (El-hawary 2014). The goal is to improve monitoring, analyze water consumption, and save water use utilizing enhanced accuracy, quick meter reading, and leakage detection (Sensus 2014).

Smart Water Meters and Benefits

Smart water meters collect and communicate up-to-date water usage in real-time (or very near to real-time) automatically and electronically (Hauber-Davis and Idris 2006). Current data networking technologies, such as wireless data loggers and mobile phone technology at the meters, enable data collection from any computer (Hauber-Davis and Idris 2006) and a centralized location for analysis or uploading to a website for customer use. The use of smart meters allows the collected data to be available to a large audience such as facility authorities, utility managers and consumers. The resolution and data logging frequency of water meters in the system determine the level of detail regarding water consumption information (Byeon et al. 2015). Implementation of large-scale smart metering utilizes affordable standard resolution water meters (i.e., 1 pulse per liter), which typically log data at 1-h intervals. These meters produce data that aid in identifying time-of-use, peak demand periods, and the occurrence of leaks. Very high-resolution meters (e.g., 72 pulses per liter) will be available in the future that can transmit second-by-second data to information systems via general packet radio service resulting in detailed accumulations of data such as itemized water usage (Willis et al. 2009).

The associated variable speed pumps detect changes in water flow and pressure, which increases or decreases its speed to maintain a specific pressure or flow setpoint. Smart pumps can also be utilized to detect clogs in the system and respond by reversing flow to break up the clogs. Automated pumps have been cited to deliver up to 70 % cost savings over the life cycle of the pump by one manufacturer (Brzozowski 2010). Additionally, reductions in water waste in landscape irrigation can be achieved by using smart irrigation controllers. By integrating information such as soil moisture levels and weather data, irrigation schedules are updated daily and creating more efficiency (Mutchek and Williams 2010).

By feeding smart water meter data to remote monitors installed in a customer's home or business, individual users are better able to identify leaks and provide a continuous reminder of the need to conserve water. Smart water meters can help jurisdictions limit the maximum water use per week or day. Initial research has shown that customers are more likely to use less water when a remote monitor is installed in their home or business (Oracle 2009). By tailoring the information displayed for each user such as neighborhood usage comparisons or month-to-month usage, consumers may be able to achieve increased water conservation (Oracle 2009).

Based on water meter information, consumers can justify investing in a new appliance that is more water efficient than existing appliances and make behavioral change to reduce water usage (Victorian Water Trust 2010). Although there are no any data available about the efficacy of smart water meters, studies on smart electricity meters have shown 5–15 % reductions in consumption by consumers receiving direct feedback and up to 10 % reductions by consumers receiving indirect feedback (Gartner 2009).

Multi-meter systems that combine water and electricity are also on the rise. For example, Garden City, Kansas, has two flexnet base stations that store and analyze data on both water and energy (Sensus 2011, 2012a, b). Sagemcom working on the EU Urban Water project plans to connect multiple metering devices to the core server that accepts multiple wireless technologies simultaneously. Demand SMART and Sensus FlexNet are demand-response applications that provide real-time feedback on resource consumption, and regulates usage by reacting to variable demand for both water and electricity (Brzozowski 2013; EnerNOC 2013; Lipski 2011; Siano 2014).

Other than smart water meters, the components of SWG development differ from country to country. Countries that have installed the AMI for water include but are not limited to the U.S., Australia, Israel, Malta, Portugal, Japan, Singapore, and India (St. John 2012; Saboo 2013; DeLay 2014; Dean 2013). Spain, France, the UK, and the Netherlands have test sites for Europe's smart water project that include leakage control, water quality management, energy optimization, and aging pipe network replacement (Volkwyn 2013). Table 1 delineates countries with major investment in SWG development and challenges and solutions.

Barriers

Cost is a significant barrier to SWG development. Smart water meter systems would cost millions of dollars to update, install, and maintain (Blom et al. 2010). Upgrading every water meter to a smart water meter involves several steps. The water retailer must purchase the smart water meter device (e.g., transmitter, data logger) and pay for installation. 90 % or more of the project cost is in the purchase of the necessary equipment, such as the meters, sensors, and radio modules, as well as the information technology and data analytics solutions to effectively manage the AMI data (Delay 2014). The leadership of utilities must decide whether to manage the transition themselves or outsource the project. While self management seems likely to minimize expense, the cost of project completion and duration may rise significantly due to a lack of dedicated and experienced expertise, impacting project quality and success. Utilities with a lack of experience in conducting a major technology transition can easily underestimate the overall impact to their organization (Delay 2014).

Security is a critical issue that requires regulation and technological innovation. In order to capitalize on demand-management models, users must have easy and regular access to their consumption data. Yet access to this data has raised anxiety about the influence of such information on user behavior. Social media can take advantage of user access to smart meters (Boyle et al. 2013), and third parties may misuse user information (Stop Smart Meters 2011). The AMI collects both personal information and water consumption of existing users. When they are combined, lifestyle and water consumption patterns can be identified in real-time (Kim et al. 2014) and used for targeted advertising, theft, or stigmatization of a particular group or community (Boyle et al. 2013; Giurco et al. 2010). Anti-smart meter movements have cropped up in some areas, notably California, to resist the expansion of smart readers (Stop Smart Meters 2011). New protocols and encoding need to be developed to configure the system in a way that prevents outsiders from identifying pertinent information (Water Innovation Alliance 2012).

Another major problem related to the adoption of the SWG is the perceived complexity of the smart water system and the challenges of new technology adoption. Many users find the smart meter system difficult to understand and access (Kim et al. 2014). Water and wastewater treatment facilities avoid installing smart equipment because people consider the installation, operation, and maintenance to be more complex and risky (Blom et al. 2010). End users also request quality and reliability tests before installation. For example, intelligent metering networks would require the ability to transfer thousands of data packets per day. Transmission issues such as wireless network reliability, black spots, power source and battery life, damage by users, water proofing, and cross connections can surface and lead to questions of reliability (Boyle et al. 2013).

This problem is more acute in less developed countries. In addition to significant institutional and regulatory constraints, major barriers result from the slow rate of technical assimilation and power breakdowns. The most prominent concern is how to operate smart meter systems when power supply is uncertain. If a backup communication network is available, a different communications protocol via a different network may be used. An alternative solution is to utilize decentralized and lower forms of technology such as manually operated treadle pumps and the use of other power sources (Jury 2005).

Another challenge is the difficulty of integrated water management that incorporates the AMI service delivery, technical capability, and governance. No quick or easy solutions exist. External experts, local scientists, and people in the community can cooperate, exchange information, and ponder solutions. While the key to addressing these issues ultimately lies within the less developed nations themselves, the means for merging local, indigenous knowledge with experience from the more developed nations can be explored (Jacobs 2015). This is especially important when the SWG can manage efficiently wastewater treatment to conserve water and help increase the provision of potable water.

Solutions

One solution to major barriers such as cost and adoption issues is educating consumers on the benefits of using SWG. Improving water literacy can help customers develop a greater understanding of their consumption and acceptance of the new technology. Designing workshops and publications to inform users about system complexities similar to the outreach programs of the electric grid can alleviate customer anxieties and foster the efficient use of the system. For example, Austin Energy using the electric grid provides customer services ranging from a call center to customer notification including postcards, customer calls, door hangers, local news coverage, special newspaper inserts and social-service agencies (DOE 2014). After

Table 1 SWG technology, investment, challenges, and solutions by country

Country	Technology used	Investment details	Challenges faced	Solutions
USA	AMI (Advanced Metering Infrastructure); CAM (Continuous Acoustic Monitoring)	USD $8.8 billion from industry funding, American Reinvestment and Recovery Act (DOE 2014)	Building a sustainable and efficient water infrastructure that uses catchment and harvesting from surface, groundwater, rainwater, and stormwater sources	Growth of smart water meters, smart-irrigation system in Santa Clarita parks with efficient water usage; Tallahassee, Florida smart utilities with centralized smart grids for water, natural gas and electric (Nichols 2010a, b; Stock 2011)
Australia	Small scale use of AMI; AMR (Automated Meter Reading) meters installed in residences (McPhee 2014)	USD $140 billion dollars: USD $11 billion for Water Smart Australia, USD $140 million for raising national water standards, and USD $140 million for community water grants (McPhee 2010)	balancing urban and agricultural demand of water and water related efficiencies during drought (DOE 2014)	the significance of geographic features in water supply including stormwater capture and reuse, aquifer recharge, pipeline usage, and urban water infrastructure upgrades with AMI/AMR meters, centralized water distribution and catchment, community-based water planning (DOE 2014)
Korea	AMI; leakage estimation models; emergency isolation valves; corrosion control technology; ICT-based (Information and Communications Technology) GIS (Geographic Information Systems) and SCADA (Supervisory Control and Data Acquisition) (SWG 2014)	USD $11 million invested in 14 projects; USD $2.5 million invested in SWG research and development	Diverse-scale implementation of SWG, optimal distribution of multi-sourced waters (SWG 2014)	SWG implementation plan: multi-housing/industry complex, city, county, and watershed; ties with water institutions such as Han River Flood Control Center, Agricultural and Fisheries Center, K-Water (SWG 2014)
Spain	Remote water meters, GIS, remote control information, water quality monitoring sensors (Berst 2013a)	SmartWater4Europe total project funding of USD $1.1 million, with USD $2.8 million going towards ACCIONA (infrastructure, renewable energy, water services company) for work in Caceres, Spain (Berst 2013a)	Minimize water leakages, efficient distribution of drinking water in the city (Berst 2013a)	real-time leak detection and usage data, a mathematical model to predict the network's usage dynamics (Berst 2013a)
India	Advanced, automated meters provided by Itron in New Delhi and Mumbai, mobile support: improved infrastructure and customer service (water-technology.net 2013)	Suez Environment and Indian Infrastructure Company: USD $95 million for a 12-year contract to improve water distribution in Malviya Nagar of New Delhi and in Mumbai, as well (water-technology.net 2012	Reduce water loss, improve water distribution and customer service (water-technology.net 2013)	100 km of 200 km pipeline renovated for the Malviya district of New Delhi, with the addition of 26 km in extensions; 120,000 Itron advanced automated meters, 40,000 standard meters, and mobile data collection software installed; call center established; water losses cut in Mumbai by 50 % and to be cut from 77 % to 15 % in New Delhi (Berst 2013b, water-technology.net 2012)
Mexico	Elster's EnergyAxis smart grid solution with AMI (Elster 2011)	USD $405,000 grant provided by U.S. Trade and Development Agency to support smart grid implementation in Mexico City (USTDA 2012)	To include water metering in a city-wide smart grid (Elster 2011)	The Comision Federal de Electricidad (CFE) has deployed nine EnergyAxis systems in 14 of Mexico's 16 service areas; the CFE expects to expand EnergyAxis for gas and water coverage (Elster 2011)

education, a low percentage of customers call in with questions and request accuracy tests. SWG demonstrations can also be used to highlight the development and implementation of SWG system, and can serve as long-term financial and technical support for SWG initiatives (Water Innovation Alliance 2012).

As for the cost, it is difficult to provide an easy solution to the installation cost of SWG. One way to overcome the cost barrier is to provide information for users to understand the benefits (Blom et al. 2010). The dynamic pricing as demonstrated with the smart electric grid, for example, can provide the customer with pricing information for current and future time periods. This allows the customer to modify his/her demand (Smith 2009). The economic impact studies are also useful especially when they emphasize the cost savings from leaks and pressure-related improvements that range from USD $2.4 to USD $4.8 billion (Sensus 2012a, b). They can also emphasize long-term cost-cutting opportunities that the current water system does not offer (Mutchek and Williams 2014).

The active participation of the private sector is also integral to the adoption of the SWG. The market for smart water is at the initial stage hence innovative solutions and education are promoted. Utilities can be educated about smart water networks, the impacts on the performance of their utilities, and cost-benefit analysis of the investment in SWG (Sensus 2012a, b). By sharing data and reaching out to technology providers, the private sector can help them understand utility needs and mindsets. By coordinating with the utilities and accepting their input, technology providers can help develop marketable smart water network products and solutions. They can also develop and adopt open standards that ensure interoperability between hardware and software offerings (Sensus 2012a, b).

Due to the uncertainty of cost effectiveness of the SWG, many utilities are reluctant to make large investments in SWG implementation. The government could play a more significant role by providing funding for research and development of SWG for the benefit of society (Mutchek and Williams 2014). This can be accomplished by appropriating funds to utilities, private companies, federal agencies, or research institutions for pilot projects. Singapore has taken on this model, investing large amounts of money into research done at both the local and global level and in both the public and private sectors. By taking this stand they have become the leader in smart water grid implementation, allowing them to be a source of innovative solutions that can be sold around the world, which provides an economic payoff for their efforts (PUB 2011, 2012a, b).

Finally, combining smart water grid with sustainable water management is essential in order to regulate the SWG use. It can be applied to existing regulations that monitor competition, power supply, data security and privacy (Simmhan et al. 2011). Ontario's Water Opportunities and Conservation Act, for example, is designed to coordinate regulation and policy concerning sustainable water management, and includes water sustainability plans, standardized information about water use on bills, water efficiency standards and a water technology acceleration project to push for innovation. In addition, new regulations are necessary to deal with the rights of the customer and the utility, specifically around issues of ownership of the assets and associated data (Boyle et al. 2013).

Conclusion

The government and private sector are two major institutions involved in the development of SWG. The goal of the government is to build an efficient network to supply water. The goal of the private sector is to construct and operate sensor networks and to manage data access and transmission. While governments have expressed support for water grids, it is seldom concrete, and policy has yet to be formulated. As SWG is a fairly new development, intergovernmental coordination and regulations are not in place yet. The private sector also hesitates as the companies are weary of transitioning into a new, costly system. What has happened so far is the establishment of several pilot projects and test centers across the world.

This limited review of SWG development, challenges and solutions provides an initial assessment of these early attempts at operating SWGs. Because the potential benefits of SWGs may outweigh the costs of installation and privacy in the longer-term, it is important to pursue SWGs to save and distribute water efficiently and widely. So far the majority of issues has to do with the adoption of SWGs such as the cost and complexity of new technology. What needs to be considered as SWGs are being continually developed is to understand and anticipate emerging issues following implementation. Some of them are discussed here, and include security, privacy, consumer literacy, and varying levels of development within and across countries. Further studies may benefit from insights from smart electric grids and integrated water management. These insights and know-hows can be applied to prepare for solutions to potential barriers in the implementation of SWGs.

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