THE IOTS APPLICATION IN WATER: AN ENABLED IOTS FRAMEWOK FOR WATER DISTRIBUTION SYSTEM

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THE IOTS APPLICATION IN WATER: AN ENABLED IOTS FRAMEWOK FOR WATER DISTRIBUTION SYSTEM

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ABSTRACT

The Wireless Sensor Networks (WSNs) and their systems are widely and increasingly applied in the pipeline network. They are helping engineers to solve problems about monitoring, control networks, enhancement of management and planning. However, regarding to the characteristics of large scale water distribution system, it will be hard to apply WSNs to guarantee data acquisition and communication safely if any nodes have transfer problems. And as the WSNs are relatively small and close networks, the WSNs systems are not sufficient to collect other kinds of data which could also influent the water distribution systems' design or operation like behavioural, social, economic and social-domestic data etc. These drawbacks for WSNs drive the upgrade of their systems into IoTs (Internet of Things). This paper particularly reviewed and evaluated the current WSN's strengths and weakness of the water industrial applications. This study presented an application framework using IoT technology in water distribution area as an IoTs application for water. The framework is expressed by five layers to offer an opening network for management, the solutions of analyzing data and the method to use data properly. The IoTs application framework can be enhanced for the pressure of pipeline network management, pump operation optimization, leakage control or prediction, serge pipeline network and water resource management as well. Also, the IoTs application framework will benefit for comprehensive optimization for water supply and distribution system from the resources until taps of household, including water quality, pressure, construction background of the pipe, social, and behavioural data etc. Combined with effective data analytical methods, the IoT framework provides intelligence to improve efficiency, communication and engaging for customers with developing new water management strategies.

Keywords: Wireless Sensor Network; Internet of Things; water distribution; Modelling; Framework

1. INTRODUCTION

Wireless sensor networks (WSNs) are increasingly gaining impact in our day to day lives (K. Romer and F. Mattern, 2004). With the development of water industry, wireless sensor networks have attracted significant research interests and considered to be the first-hand in many civilian applications such as leakage detection, sewage management, and water supply optimization etc. (Tariq AL-Kadi, 2013).

There will be no doubt that the WSNs technologies have advantages for application compared to non-WSNs techniques such as: tracer gases, ground penetrating radars, acoustic sensor, geophones and microphones. The WSNs are wireless which offer a relatively safe running environment and avoid the risks that unauthorized person disable the system by cutting the wires. And recent research of WSNs for water shows that the WSNs technologies can offer low-cost and high accuracy signal in application (A. J. Whittle et al., 2013). Specifically, advantages for WSNs can be summarized as follow: easy setups without infrastructure limitation; non-reachable placement likes across forests, sea etc.; flexible for control and management; cheap implementation cost; easy capture for variable data with different sensors. However, according to the WSNs research in water industry area, it has drawbacks as well (Debnath Bhattacharyya, 2010). The wireless sensor network has risk on security as the access points in the network are relatively small and close. If hackers enter those points, the system will be exposed under hack risks. And compared to a wired network, WSNs are more complicated to configure and easier to be affected by surroundings such as microwave, signal attenuation etc. Also, the transfer speed is slower in close and wireless networks. In the near future, WSNs are expected to be upgraded into the "Internet of Things" to overcome those drawbacks.

This study reviewed some research about WSNs and IoTs applications in water industry. The methods for integration and upgrade WSNs to IoTs are proposed as well. To better understand IoTs and its applications for water, a framework to manage leakage in pipeline is developed as an example. This framework contains the model of leakage analyses and simulation, the detection and warning tools of leakage. IoTs technologies will be benefit to monitoring and warning the leakage in the pipe by supporting with big data analyses. The effect of this system for leakage control is significant by considering its IoTs warning function. Moreover, the cloud analytical platform can guide the engineers with correct and reasonable action plans.

With the IoTs's support, the framework helps systems obtain data about the leakage from all sides. Big data technology cooperated with the new advanced analytical models, analyses the data and gives early warnings to the engineers, even with the cause analyses and prediction for a single leakage cases. In the analytical model, all the data in the IoTs servers will be classified and be used to analyses the risk of leakage and pointed out the leakage zones in the platform with different colors. When there was a pipe occurred leakage problems, this platform will offer a report contains all the possible causes and damages to the accidence in time. In addition, to be an extended of big data service, all users could upload their pipe or community construction information to the leakage zone ID (Leakage areas identified and classified by different level of risks), even their behavioural change information towards the water consumption. We can use all the data generated by another big data management and control model in the platform to guide our users to change their water use behaviours such “Do not use too much water in the peak hours”, change the pressure in the pipe or application of ladder-like water price strategy. And this will help the water utilities to manage the water pressure and minimalize the losses of leakage from some other aspects.

We believe that this framework will solute the problems of leakage cloud analyses (decision making) and help the water utility better manage the water leakage in the future. It is also suggested in the paper that this framework has potential to be used in the other areas of water science. The major contributions of this study are summarized as follow:

1. Application of the IoTs in water industry.
2. Development of a new real-time warning/control network for water management based on the IoTs and internet.
3. Modelling solutions for leakage condition of the water supply network.
4. A review for WSNs’ drawbacks and IoTs applications for water industry.

2. WSN FOR WATER

A large number of WSNs applications for pipeline monitoring have been developed in literature (Bensaleh, M.S, 2013, Seddiq, Y.M., 2013) such as oil, gas and water/waste water industries (Debnath Bhattacharyya, 2010). Jawhar et al., (2007) presented an initial framework for using linear WSN for pipeline monitoring. A WSN for pipeline monitoring typically consist of sensor nodes and router nodes. And by using these two kinds of nodes, the network transfer and interconnect in linear or tree shape to guarantee the data aggregation and processing. Figure 1 shows the basic structure of WSNs.

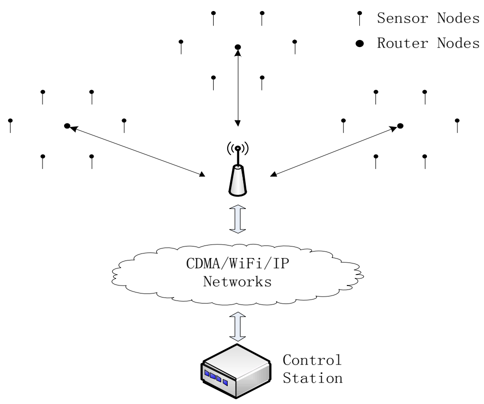

Figure 1. The basic structure of WSNs

In the WSN literature, there are five different areas for WSN applications in water industry: pipe monitoring, water distribution network monitoring, waste water network monitoring, water quality monitoring and end use monitoring. Mohammed S. Bensaleh et al., (2013) discussed the pipeline monitoring architectures classified by the network connectivity. Y. Kim et al presented a nonintrusive autonomous water monitoring system named NAWMS. NAWMS used PipeNet to quantify, locate and detect leakages in the pipe. The underground wireless sensor network in that research is applied to measure vibrations and provide operation condition with few alarms. TriopusNet, proposed by T.T. Lai et al., (2012) is comprised by centralized repository sensor nodes which are in the pipe and flow forward by flow. Three arms node can attach the inner face of the pipe in order to get a highly accurate water flow data. Leakview water leakage monitoring system, developed by Anheng Group, China, upgraded the WSNs into IoTs by using RFID, GIS, mobile phone and internet management platform. The Leakview system could obtain real-time pipe network operation condition and leakage alarms. All relative staffs and costumers are free to have leakage locations and further notices of maintains. Leakview system has been proved to be successful for minimize leakage rate (about 50%) in an urban community. Compared to NAWMS and PipeNet, the Leakview network is more flexible and can guide the maintainers with instant incident notices to their mobile devices via internet.

Michael Allen et al., (2003) presented the WaterWise platform supported with WSNs to monitoring the water distribution system. The primary data source is a wireless sensor network which is deployed on pipes within distribution system, providing online update of the hydraulic and water quality. The WaterWise system allows water suppliers across a variety of important applications, such as leak detection, water quality monitoring, online hydraulic calibration and others. Waste water networks and water quality monitoring networks are also been studied by using the WSNs (K. A. Unnikrishna Menon et al., 2012, Victor-M. Sempere-Paya et al,. 2012, Jer Hayes et al., 2007). Blue Box Tool (ACQUEAU, 2010) and Neptune Project are two examples focus on monitoring water quality, prevention and early action in case of contamination.

3. WSN TO IOTS

By reviewing the literature for WSNs applications for water industry, there are several unavoidable drawbacks for this technology. Those drawbacks are common for WSNs but expected to be fixed by IoTs. Take the water leakage management for instances, a precise leakage accident could be caused by pipe ageing, high water pressure, incorrect construction methods etc. The current leakage models based on the WSNs can only collect data with geographic, weather, engineering aspects. This could limit the system to use all the other useful data (ageing, location etc.) to analyses the operation condition more effective. Moreover, the cooperative operation within different water monitoring or management systems (like SCADA) is still a problem for water distribution integrated management purposes. The cooperation supports the information exchange between various actors through internet. Current WSNs for water cannot achieve the multi-agent information sharing as those networks are designed for just one or two engineering purposes and facing difficulties of integration.

The WSNs system is not smart and open enough. The Internet of things, as higher application level of WSNs, could connect the WSN to the other elements which offer the WSNs a solution for more open access. All users could check and view the operation condition of the pipeline system on time via their devices like mobile phone, laptop, computer, ipad etc. They can be informed of the latest notices form the water company about pressure change, the price change or some other management strategies as well. At the same time, the users could report incidents like leakage to the water company through the internet. Moreover, it will be convenient for engineers to maintain or repair the pipes in time if they could be noticed by phone calling or texts.

The systems based on WSNs are not sufficient enough to collect and analyse data concerned every aspects. Take the water leakage monitoring networks as examples, the current WSNs systems are designed to collect and analyse data with engineering purposes. However, engineers should be aware of that a precise leakage incident could be caused by many reasons. Some parameters, such as pipeline ageing, house location, consumer behaviours etc. should also be taken into account. Moreover, a precise WSN for pipe leakage monitoring are also designed without considering further integration of other systems. This will be an obvious drawback to apply big data analyse technologies to WSNs management platforms.

The wireless sensor network is facing to security risks because there is not a precise standard for sensor network protection. For the data transaction with long distance pipeline, normally, sensor nodes connected with router nodes in figure 1 can be regarded as the most common network lay out method. But if some core router nodes collapse, the data transaction of a district will be effected or interrupted. With the support of internet connection, WSNs data transaction risks could be minimized in IoTs. Every sensor could communicate and transfer data independently via internet.

With the needs of comprehensive water management, water utilities are seeking technologies for integrate current management systems and make them cooperate more easily. The water is expected to be monitored from river to tap. Cooperative operation and data sharing are essential for making this plan come true. The cooperation supports the information exchange between various actors through internet. Current WSNs for water cannot achieve the multi-agent information sharing as those networks are designed for just one or two engineering purposes and facing difficulties of integration.

4. CURRENT RESEARCH

IoTs as advanced technologies have been investigated by many water companies and research institutions. The Internet of Things paradigm aims to bring intelligent interconnection of objects in the physical world through information sensing devices, such as RFID tags and communicating sensors connected to the internet (H. Chaouchi, 2010). As identified by Atzon et al., (2010) IoT can be realized in three paradigms: internet-oriented (middleware), things-oriented (sensor) and semantic-oriented (knowledge). Figure 2 shows the end users and the application areas of the Internet of Things (Jayavardhana G, 2013).

The IoTs technology already has been applied in the water industry partly. We spilt the IoTs application in water industry into two parts. One obvious part is the WSNs or RFID. A huge amount of projects have applied WSNs. Boston Water and Sewer Commission (BWSC) deployed monitoring system to evaluate nodes and gateways of water system in 2004. University of Maryland in 2014 designs the model-based systems engineering for cyber-physical system and implement that the WSN and the CPS can help a lot about the water industry in pipe monitoring. The institution of Professional engineers in Fukuoka City proposed the water leakage prevention measure from water pipes in Fukuoka City project by using WSN and it has been proved very effective. The other application or development for IoT in water industry is the internet connection of former network. Likes the SmartWater project in Staffordshire University, UK, by uploaded the data to the internet. Every decision maker could visit the website or servers with account information with the real-time data and the results of calculation from the models.

It will be possible to implement the IoTs technologies into leak management. A lot of research already proved that IoTs could be implemented for water industry (Shifeng Fang, 2014). All the data can be stored in the data warehouse and share by internet. This will support all the aspects in the IoTs to use data for leakage warning and management purposes. RFID tag can be put on the mobile devices to tacking the engineers whether the problems could be solved or not and how long it could be to solve them. Communication between things allows the engineers to work together or discuss on the internet as well. Figure 3 shows the communication clues of the internet of things for leakage (Ali M. Sadeghioon, 2014). And we believe the IoTs will meet the requirement (Real-time; Scalability; Connectivity – to allow sensors connectivity to enterprise IT systems; Support for dynamic environments; Security.) of the water utilities for the next generation of SCADA system.

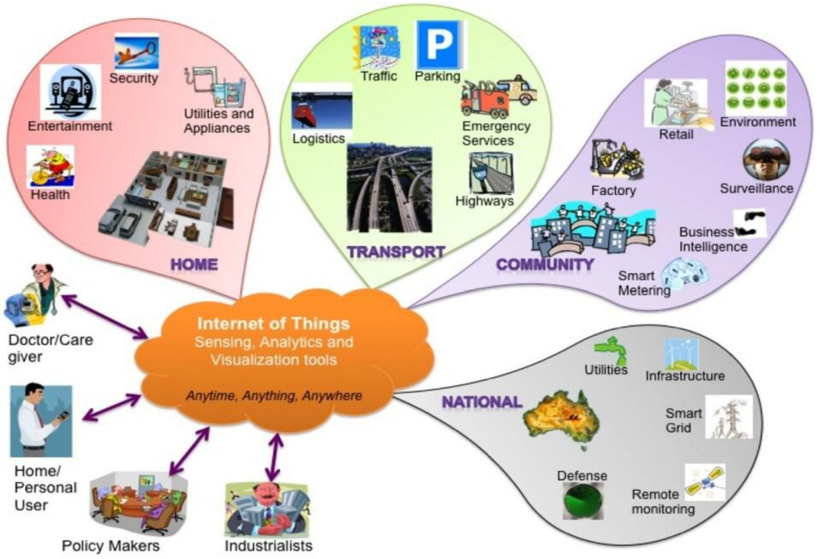

Figure 2, The end users and application areas of the Internet of Things (Jayavardhana G, 2013).

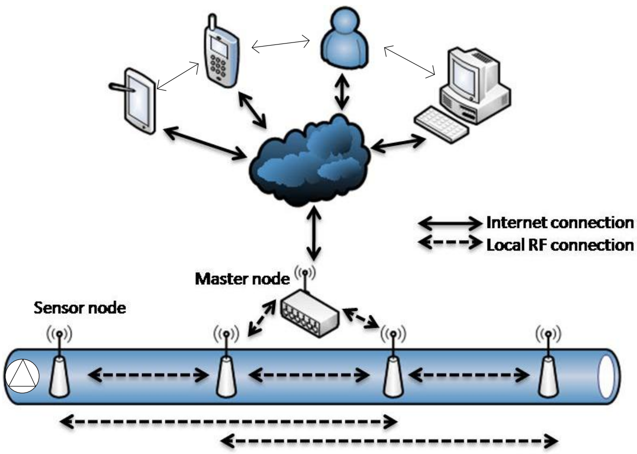

Figure 3, Communication clues of the internet of things for leakage (Ali M. Sadeghioon, 2014)

5. IOTS FRAMEWORK ARCHITECTURE

In this section, the architecture of sensor network for this enabled framework is presented. Network deployment, setup, discovery and maintenance are discussed. According to the international telecommunication union (ITU) specification, the IoTs framework is classified into five different layers: perception layer, access layer, internet layer, service management layer, application layer. Specifically, the perception layer is applied for obtain various types of the real world by sensors etc. Access layer is a local network for sending data from perception layer. And the internet layer is to establish an infrastructure platform for upper-coming management and control via internet. Service management layer is to get information within cluster server network to provide user interface for upper layer application. Then in the application layer, integration of underlay system functions and practical application development are achieved for water distribution network management. Figure 4 shows the five layers for the enabled IoTs framework.

Ideally, in this framework, at the perception lay, monitored points should be chosen not just by following the engineering principles but also should consider the position of "big consumers" such communities, faculties, hotel, hospitals etc. in order to monitor the leakage and operation condition more accurate. When every monitored point has been chosen, sensors with RFID tag then physically installed. The RFID tag with geographic information, install data, maintainers name, pipe history and leakage history is read remotely by RFID reader. Also, GPS sensors with location data transferring are suggested to be used in the sensor network. Internet functional interface should be considered to be one of the important parts of perception layer as well for acquiring "no-engineering data": social data, economic data, leakage data (history, construction methods, accident reports) and costumer' files etc. Figure 4 shows the relationship of different types of nodes. Each sensor and RFID tag collects data from pipe and they many relate to leakage parameters such as pressure, water flow rate, location information, leakage history and so on. In order to gain continuous leakage parameter data for analyse, sleep and wake-up times for all sensors should be selected at network configuration time. Bluetooth and IEEE 802.15.4 (Zigbee) are suggested to be used as sensor network standards and should be regarded as suitable for this framework. In the sensor network, every sensor has connects and communicates by internet dependently. This kind of connection and communication is known as WLAN (IEEE 802.11g and IEEE 802.11n), which is a standard offering data rates up to 54 Mbps and 600 Mbps respectively (Mir Saleemullah Jamali, 2014). WLAN structure with internet connection support in Figure 5 makes solid access point network. For network safety purpose, wireless sensor network architecture can be applied to guarantee the data transfer when the system internet connection down. Geographic distances between nodes, node hierarchy, hop and ship protocol in this framework can be referred by network connection of WSNs.

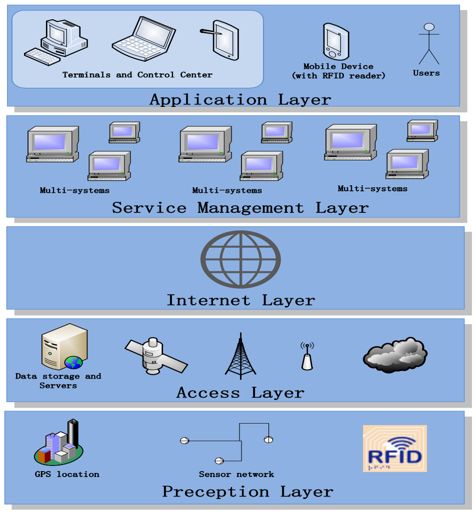

Figure 4. The five layers for the enabled IoTs framework

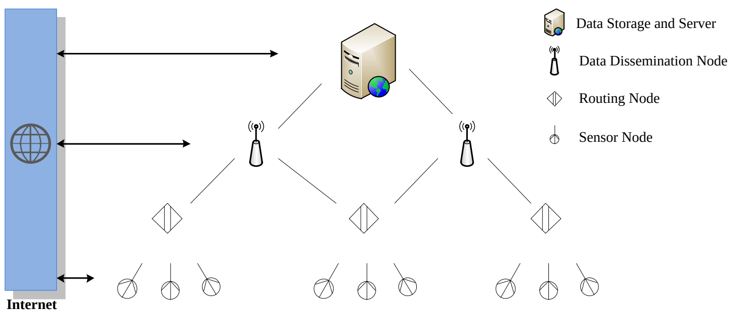

Figure 5. The relationship of different types of nodes

6. MODELS AND DATA PROCESSIN

Data in this framework is ideally collected from all related recent WSNs and internet. Integration of WSN and internet should be taken into account firstly. To integrate WSN into internet, stack-based and topology based approaches (Chritina Alcaraz, 2010) are suggested. In the framework, data is processed by the flow in figure 6.

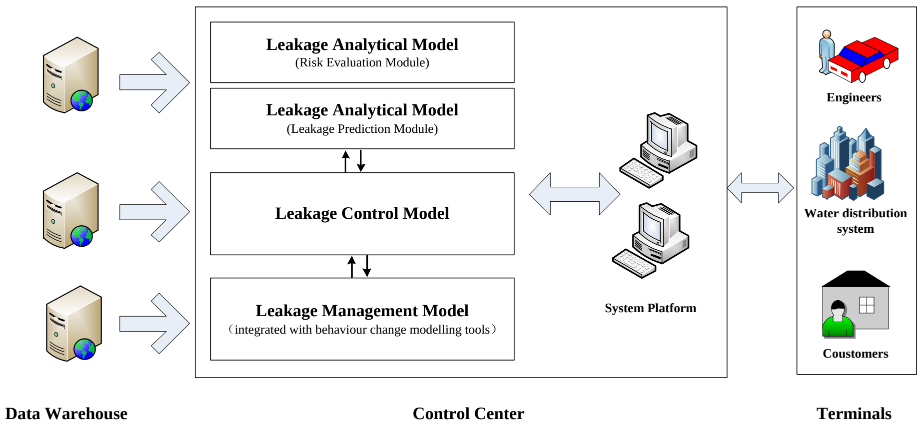

Figure 6. Data processing flow and models

6.1 Analytical Model

Data analytics in the field of water resource management is seen as the new area of study that may facilitate in optimally managing the provision of water based on availability (Prashant Shrivastava, 2014). Data analytics contains data management, exploratory analytics, and data visualization tools and help discover important characteristics of highly-complex water systems (Dragan Savic, 2013). The analytical leakage model in this framework analyses all the factors will lead to the leakage: engineering parameters, social, economic, geological data.

The data analytical model contains the module of risk evaluation and the module of prediction. The module of risk evaluation is the module to evaluate the risk in different areas based on the data on the servers. The DEMATEL (Decision Making Trial and Evaluation Laboratory) and INRM (Influential Network Relation Map) will provide technological supports for this part. And the module of prediction is based on the data by using the Box-Jenkins technique.

The mechanic of leakage risk evaluation is discussed as follow: At the first, the real-time data with pressure information and the leakage information will be sent to the data warehouse. And all the factors could lead to leakage likes the location in the pipeline network, the pipe age, load of pipe, solid condition and movement, pipe materials, pipe diameter, the historical leakage records of this zone, the feedback from the users etc. will be loaded to the data warehouse at the same time. Then, DEMATEL (Decision Making Trial and Evaluation Laboratory) is used to construct the INRM (Influential Network Relation Map) and present the relationship between the leakage accidents and the factors what may lead to the leakage. Thirdly, the analytical results from different layers of risk evaluation are uploaded to the open platform for sharing.

There are three parts among the module of prediction: the AR-Autoregressive process, I-Integrated, MA-Moving Average for the forecast errors (Prashant shricastaca et al., 2014). It has 3 parameters, one for AR process, one for I process, and one for the MA process. All parameters are interacting among one another from Box-Jenkins. And the model gives prediction value during a latency series that is linear combination of its own past values and current and past values of alternative time series.

6.2 Management and Control Models

As discussed above, the analytical leakage model analyses all the factors which lead to the leakage. On the contrary, when the leakage occurred, we will need another model relied on the cloud serves to manage the leakage accidents with engineering solutions, even marking strategies to solve problems.

The leakage management and control models contain three parts. The first part is to offer the leakage management strategies and reason analyses. In this part, the model will analyses a precise leakage accident with it location, pipe age, historical records, pressure records, solid etc. and give an countable report for engineers to make a decision. Moreover, with the integration of behavioural change tools, engineers or water companies can effectively evaluate all the water management strategies. The other part of this model is the control part. The water leakage lose could be adjust and minimize by change pressure in the pipeline. A lot of researches have proved that this is a sufficient method to simulate and deduct the leakage (Mosissa Meressa Gamtessa, 2008). And the pressure control could be used to monitor the leakage in the pipe (John Mashford et al. 2009). The model can give pressure solution for leakage detection and deduction. For the third part of the model, the economic analyses for the leakage, it is a tool of economic evaluation model for leakage. It is aimed specifically at determining when a water supplier should invest in active leakage control for a specific zone metered area. This tool will assist water companies to gain a better understanding of the main factor influencing the economics of leakage control and enable them to identify the most cost-effective methods of reducing leakage.

Pressure can affect system losses in a number of ways. The rate of leakage from the leaking pipe or faulty joints will increase with a rise in pressure (Mosissa Meressa Gamtessa, 2008). Conversely, pressure reduction can reduce the rate at which bursts occur. The relationship between leakage and pressure can be given below:

$$Q_2 \ / \ Q_1 = \left(P_2 \ / \ P_1\right) \times N$$

Where: Q_1 , Q_2 are the flow from the leakage at pressure P_1, P_2 .The value of N in equation has considerable effect on leak reduction program. If N =0.5, reducing pressure by half reduces leakage by 29 %; If N =1.5, reducing pressure by half reduces leakage by 65 %; If N =2.5, reducing pressure by half reduces leakage by 82 % (Mosissa Meressa Gamtessa, 2008).

The model of leakage management measures the leakage by different places (reservoirs, transmission lines etc.) and hydraulically simulate (EPANET etc.) the pressure change by the best management solution to deduce the leakage. Moreover, as the other factors could lead to the accidents, the causes for the leakage from the data analytic model will be input into the management model to offer better management solutions. In addition, with the help of behavioural change and economic tools, water companies can propose and access their strategies or policies toward the deduction of leakage. The MCDM (Multiple Criteria Decision Making) could re-access the strategy of leakage management with the help of Fuzzy Delphi Method.

6.3 Customer Behaviour Change and Economic Modelling Tools

From the management perspective, to promoting management strategies for leakage control, behaviour change technologies are integrated as modelling tools for customer behaviour intervention. All management strategies such as saving water during the peak hours, decisions from control center with proper guidance can reach every customer's devices with the help of internet and open platform. The behaviour change tool is computerized by TPB and expressed by SEM. Economic function in this tool is more likely to be an extra tool to evaluation the cost of one precise management strategy from the control center. Details of behaviour change tool are shown in reference (Yang Fu, Wenyan Wu, 2014). Figure 7 shows the data calculation methods of behaviour change tool in structure for leakage prediction model.

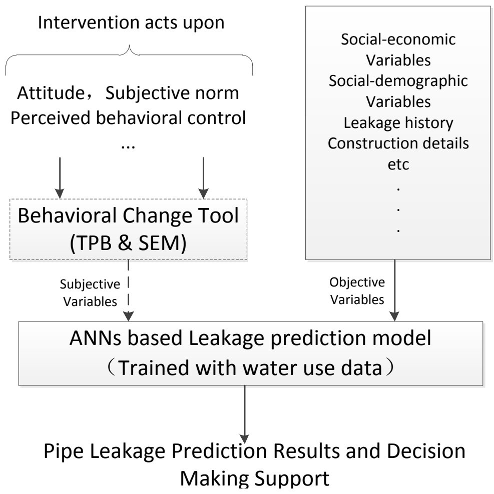

Figure 7. Behaviour change modelling tool technological structure

7. CONCLUSIONS

This paper reviewed the applications of WSNs in water industry. There is no doubt WSNs technologies have solved engineering problems and clearly shown advantages. However, compared to IoTs, drawbacks of WSNs are obvious as well. The internet of things is potential and suggested to be the next generation application solution in water industry. It also has several challenges related to standardization, architecture, interconnection, security and integration between other wireless sensor networks and control systems. The IoTs enabled application framework with intelligent leakage management models is proposed. It could be applied to some other related areas likes water, waste water, reservation management in water industry. Further research are planning to be done for sensor network specification and modelling designs.

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REFERENCES

A.J.Whittle, M.Allen, A. Preis and M.Iqbal, Sensor Networks For Monitoring And Control Of Water Distribution Systems, *The 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, 2003, 9-11.

Alcaraz C, Najera P, Lopez J, et al. Wireless sensor networks and the internet of things: Do we need a complete integration?, *1st International Workshop on the Security of the Internet of Things (SecIoT'10)*. 2010.

Ali M. Sadeghioon, Nicole Metje, David N. Chapman and Carl J. Anthony, 2014, SmartPipes: Smart Wireless Sensor Networks for Leak Detection in Water Pipelines. *Journal of Sensor and Actuator Networks*, Actuator Netw. 2014, 3, 64-78.

Atzon, L.; Iera, A.; Morabito, G. *The internet of things: A survey*. Comput. Netw. 2010, 54, 2782-2805.

BenSaleh, M.S.; Qasim, S.M.; Obeid, A.M.; Garcia-Ortiz, A. A Review on Wireless Sensor Network for Water Pipeline Monitoring Applications. In Proceedings of *the International Conference on Collaboration Technologies and Systems (CTS'2013)*, San Diego, USA, 20-24 May 2013; pp. 128-131.

Christin, D.; Reinhardt, A,: Mogre, P.S.; Steinmetz, R. Wireless Sensor Networks and the Internet of Things: Selected Challenges. *In Proceedings of the 8th GI/ITG KuVS Fachgesprach Drahtlose Sensornetze*, Hamburg, Germany, August 2009; pp. 31-33.

Debnath Bhattacharyya, Tai-hoon Kim and Subhajit Pal, (2010), A Comparative Study of Wireless Sensor Networks and Their Routing Protocols, *Sensors* 2010, 10 , 10506-10523; doi:10.3390/s101210506.

H. Chaouchi. Internet of Things. Connecting Objects. Wiley and Sons. 2010.

I. Jawhar, N. Mohamed, and K. Shuaib, "A Framework for pipeline infrastructure monitoring using wireless sensor networks, in Proc. Of *Wireless Telecommunications Symposium (WTS'07)*, April 2007, pp.1-7.

Jamali M S, Kumar P, Khan U A. Internet of Things: Architecture & Integration with Other Networks. *First International Conference on Modern Communication and Computing Technologies (MCCT'14)*, 26-28 February, 2014.

James Manyika, Michael Chui. *Big data: The next frontier for innovation, competition, and productivity*; McKinsey Global Institute ,May 13, 2011.

Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, and Marimuthu Palaniswami, Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions, *Future Generation Computer Systems*, Volume 29, No. 7, Pages: 1645-1660, ISSN: 0167-739X, Elsevier Science, Amsterdam, The Netherlands, 2013.

Jer Hayes, King Tong Lau, Dermot Diamond, A wireless sensor network for monitoring water treatment, *2007 International Conference on Sensor Technologies and Applications*, 514-519.

John Mashford, Dhammika De Silva, Donavan Marney and Stewart Burn, 2009, An approach to leak detection in pipe networks using analysis of monitored pressure values by support vector machine, *the 3th international conference on network and system security*.

K.A. Unnikrishna Menon, Divya P, Maneesha V. Ramesh, Wireless Sensor Network for River Water Quality Monitoring in India, *ICCCNT'2012*, July 2012.

Kleiner Y, Rajani B, 2001. Comprehensive review of structural deterioration of water mains: statistical models. *Urban water*, 3(3): 131-150.

Kun Han, Dacheng Zhang, Jingyi Bo, Zhiguang Zhang, 2012, Hydrological monitoring system design and implementation based on IOT. *2012 International Conference on Medical Physics and Biomedical Engineering, Physics Procedia* 22 (2012) 449=454.

Kuei-yang Wu, Ming-jie Zheng, Shih-chung Lu, Yen-yu Wu, Applying DEMATEL method to the study on sustainable management of low-carbon tourism for Cultural heritage conservation, *Recent Advances in Energy*, 2014, 96-102

L. Aizori, A. Iera. G. Morabiro. The internet of things: a survry, *Computer Networks*, 54 (2010) 2782-2805.

Jayavardhana Gubbi, Rajkumar Buyya, Slaven Murusic, Marimuthu Palaniswami 2013, Internet of Things (IoT): A vision, architectural elements, and future detections, *Future Generation Computer Systems*, 29 (2013) 1645-1660.

Michael Allen, Ami Preis, Mudasser Iqbal, Andrew J. Whittle, Water Distribution System Monitoring and Decision Support Using a Wireless Sensor Network, *14th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing*, 2003, 641-646.

Miorandi, D.; Sican, S.; De Pellegrini, F.; Chlamtac, I. *Internet of things: Vision, applications and research challenges*. Ad Hoc Netw. 2012, 10, 1497-1516.

Mosissa Meressa Gamtessa, 2008, Pressure modelling for leakage deduction in addis ababa water supply system mains. *Thesis to the Addis Ababa University*.

Poulakis Z, Valougeorgis D, Papadimitriou C, 2003. Leakage detection in water pipe networks using a Bayesian probabilistic framework. *Probabilistic Engineering Mechanics*, 18(4): 315-327.

Prashant Shrivastava, S. Pandiaraj, J. Jagadeesan, 2014. Cloud Based Software Platform for Big Data Analytics In Water Reservoir Level Forecasting. Journal of Computer Engineering, Volume 16, Issue 2, Ver. 7, PP 17-20.

Romer, K., Mattern, F., 2001. The design space of wireless sensor netowk. *Wireless Communications*, IEEE, Volume11, Issue 6:54-61.

Seddiq, Y.M.; Alotaibi, A.M.; Al-nasheri, A.Y.; Almazyad, A.S.; BenSaleh, M.S.; Qasim, S.M. Evaluation of Energy-Efficient Cooperative Scheme for Wireless Sensor Nodes used in Long Distance Water Pipeline Monitoring Systems. *In Proceedings of Fifth International Conference on Computational Intelligence, Communication Systems and Networks (CiCSyn'2013)*, Madrid, Spain, 5–7 June 2013; pp. 107–111.

Shifeng, Fang, Li Da Xu, Senior Member, Yunqiang Zhu, Jiaerheng Ahati, Huan Pei, Jianwu Yan, and Zhihui Liu, An Integrated System for Regional Environmental Monitoring and Management Based on Internet of Things, *Transactions on Industrial Informatics*, VOL.10, No.2, May 2014, 1596-1605.

Tariq AL-Kadi, Ziyad AL-Tuwaijri, Abdullah AL-Omarn, (2013), Wireless Sensor Networks for Leakage Detection in Underground Pipelines: A Survey Paper, *Procedia Computer Science*, 21(2013) 491-498.

T. T. Lai, W. Chen, K. H. Li, P. Huang, and H. H. Chu, "TriopusNet: automating wireless sensor network deployment and replacement in pipeline monitoring," Proc, *11th Int. Conf. on Information Processing in Sensor Networks (IPSN'12)*, April 2012, 61-71.

Weifeng Li, Wencui Ling, Suoxiang Liu, Jin Zhao, Ruiping Liu, Qiuwen Chen, Zhimin Qiang, Jiuhui Qu. Development of systems for detection, early warning, and control of pipeline leakage in drinking water distribution: A case study, *Journal of Environmental Sciences*, 2011, 23(11) 1816-1822.

Yang Fu, Wenyan Wu, Behaviour interventions for water end use: An integrated model, *2014 20th International Conference on Automation and Computing (ICAC)*, September 2014, 266-271.

Y. Kim, T. Schmid, Z.M . Charbiwala, J. Friedman and M. B. Srivastava "NAWMS: Nonintrusive autonomous water monitoring system," in Proc. of *the 6th ACM Conference on Embedded Network Sensor System (SenSys'08)*, 2008, 309-322.