DIGITALIZED WATER AND SMART CITIES – HOW CAN TELECOMMUNICATION NETWORKS BE USED FOR ENVIRONMENTAL RESILIENCE?

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Abstract *– Water is a prerequisite for life. Water can also be a problem through heavy rain causing floods and destruction. In this paper we will describe two ongoing projects where Ericsson is participating to develop digitalized water-related monitoring solutions. One project relates to real-time rain detection through telecommunication microwave networks and the second project is the development of an IoT-based real-time water quality monitoring solution for smart cities. We will also elaborate on the opportunities and positive impact, as well as challenges and needs for the full integration of such solutions in cities.*

Keywords – Internet of things, microwave, rainfall monitoring, smart cities, telecommunications, water quality monitoring

1. INTRODUCTION

The upcoming decade will most probably be a game changer in how digital data is utilized in the world. The first commercial 5G networks will be launched during 2018 resulting in a drastic change in how data can be transported between machines and between users. The introduction of 5G and low power networks will increase the number of devices connected to the Internet, where it is estimated that the number of cellular Internet of things (IoT) connections will reach 3.5 billion in 2023. Monthly data usage is expected to reach 107 exabytes by the end of 2023 [1].

The future for connected devices and their applications looks bright. Higher speeds and lower latencies through 5G networks will, for example, enable the use of autonomous vehicles and remote control of machines [2]. Smaller and simpler devices connected to the Internet will increase in numbers and the data generated will be used for decision making, whether it is to increase the temperature in your home remotely or the management of an entire network of a mass transit communication system. Utilizing IoT and digital data to monitor the environment and predict potential upcoming concerns, such as pollution flows and climate-related disasters, can increase the efficiency for mitigation actions. Through the availability of real-time data, awareness can be raised in businesses and society.

Water is a prerequisite for life, but it can also pose a risk to societies and the environment. It is expected that rainfall will increase in intensity in many parts of the world due to climate change [3][4], potentially resulting in floods and landslides resulting in societal costs and potential risk to lives. Several cases of severe flooding have occurred in Sweden over the last 5-10 years, and a major flooding disaster took place in Copenhagen, Denmark in July 2011 when 120 mm of rain fell in 2 hours and led to damages associated with estimated costs of up to 1 billion EUR [5].

On the other hand, access to clean and safe drinking water is a necessity for societies, where only 2.5 percent of all water on earth is fresh water. Out of these 2.5 percent, approximately 0.4 percent can be used for consumption [6]. Hence, water for citizens' consumption is an emerging issue in many cities around the globe where knowledge of the ecological and chemical status of rivers and lakes is an important tool to be able to secure safe water for citizens. In the EU, water quality in lakes and rivers is regulated through the Water Framework Directive [7] and the WHO has determined water quality targets and thresholds for safe consumption [8]. However, recent studies have shown that many water areas in, for example, Sweden do not live up to the requirements in the directive and some have even deteriorated [9].

To be able to understand and mitigate water-related risks, data is needed to be able to take informed decisions. Precise and accurate, real-time data can be used to perform better weather predictions and forecasts as well as to understand water-borne pollution and to be able to develop well-functioning early warning systems.

Today, the collection of water-related data is either manual, costly or with inferior resolution. Different methods for the collection of rain data exist, where rain gauges have, historically, been a major source. However, in the past fifty years, weather radars have been used, mainly in developed markets while satellite surveillance is the main tool for tropical regions. All these methods have their pros and cons, where, for example, gauges can provide accurate data but suffers from low spatial resolution. On the other hand, radar measurements can provide a better spatial coverage, but have limitations in time resolution and rain intensity measurements. Water quality measurements are mainly manual sample collections with a following laboratory analysis, resulting in precise data but with the disadvantage of long lead times between sampling and result.

Can modern telecommunication and IoT solutions be a solution for obtaining better environmental data to increase our understanding of water-related issues such as rainfall and drinking water pollution? This paper will describe two novel information and communication technology (ICT) solutions addressing water-related emerging issues, impacting the Sustainable Development Goals [10].

2. RAIN DATA COLLECTION THROUGH TELECOMMUNICATION NETWORKS

Rain fade is a well-known expression in telecommunications, referring to the adsorption and attenuation of microwave signals due to atmospheric rainfall. This has been a factor affecting the operational characteristics and performance of microwave systems [11] such as commonly used microwave backhaul in telecommunication networks. Wireless microwave backhaul is a cost-efficient solution for the transportation of voice, video and data where rain impacts have required different mitigation efforts, such as adaptive modulation and coding and other newer solutions, to secure reliable microwave networks [12]. The possibility to measure rainfall through the use of microwave links was first proposed in 2006 by Messer et al. [13] and since then various research groups have contributed to the area.

Building on these ideas, in 2015, the Swedish telecommunications equipment vendor Ericsson, together with the Swedish Meteorological and Hydrological Institute (SMHI) initiated a project on rainfall detection and measurements utilizing microwave links in commercial telecommunication networks. A 20-months' long pilot was conducted in Gothenburg, Sweden where links from the mobile network operator Hi3G Sweden were used as rain-sensing devices, where data was obtained every ten seconds, measuring transmitted and receiving power from 364 microwave hops covering an area of more than 4000 km² in the Gothenburg area [14]. This pilot included the collection and filtering of data and the development of high-resolution rain measurement algorithms for use in commercial telecommunication networks.

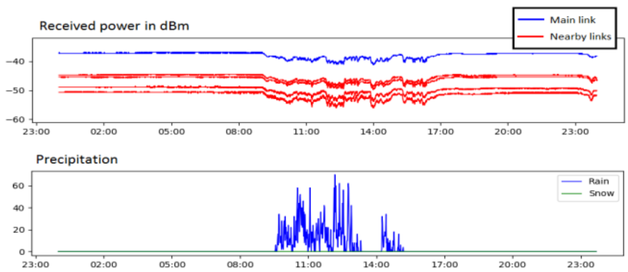

Fig. 1 – Received power over time for a microwave link in Gothenburg, Sweden, showing attenuation during a storm event.

The pilot resulted in an understanding that rainfall measurements improve monitoring by providing higher temporal resolution, greater surface coverage, higher spatial resolution of rainfall maps, better ability than radar to capture peak intensities at local scale, near surface measurement, and more robust sampling, compared with gauges and radar solutions (see Fig. 2) [15].

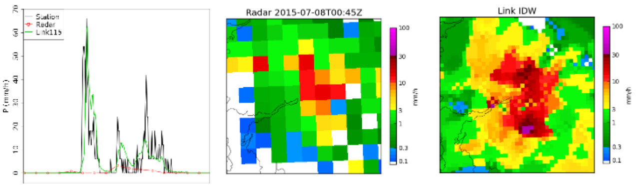

Fig. 2 – (a) Example from a high intensity rainfall on 27 July 2015. The gauge's highest recorded intensities occurred around 15:05 UTC in the one-minute gauge. The peak was also well captured by the microwave link, however, the radar failed to see any significant event (b) and (c). Rainfall intensity maps constructed for an event in July based on SMHI's radar (a) and the microwave links (b). The density of the links support a high spatial resolution, and the sampling frequency allows better measurements of the complete event, compared to the snapshots provided by the radar.

Hence the pilot in Gothenburg showed that there are possibilities in utilizing rain fade in commercial networks to measure near real-time rainfall and unlocking new opportunities and use cases for microwave backhaul solutions. However, errors, such as elevated bias and outliers remained in some situations, which required further algorithm development and fine tuning of the overall solution. Achieving greater accuracy and more consistent performance was needed to make the data more trustworthy, ultimately improving the usability for end users and to enable commercial use of the solution.

There are today no microwave-based rain-monitoring solutions running on commercial telecommunication networks. Therefore, during 2017 the project continued in a final phase to develop the usability of the algorithms as well as develop use cases for microwave-based rainfall monitoring.

Three simultaneous projects are running, in Sweden, Germany and in Rwanda with the scope to evaluate tempered and tropical climate conditions, to develop business models and industrialization for a go-to market of the solution. Furthermore, through the introduction of 5G and high-frequency (100 MHz and beyond) backhaul equipment, there is an interest and opportunity within these projects to investigate the usefulness of microwave-based monitoring for snow and fog. For these applications these higher frequencies might be needed to induce and detect signal disturbances and further broadening the use and scope of the solution.

3. WATER QUALITY MONITORING SOLUTIONS

Our second topic in this paper, will discuss water quality monitoring solutions based on digitalization and IoT. The monitoring of water bodies is a requisite to understanding environmental conditions affecting lakes and rivers and also a requirement in many regions, such as the EU. As previously mentioned in Section 1, such monitoring mainly relies on manual sampling and detection in laboratories, which takes time and hinders timely and efficient mitigation efforts and thus does not provide an early warning system for cities, water utilities and communities. To be able to take efficient actions, continuous access to improved data and information of water quality is needed, and thus opens opportunities for the introduction of digitalized water monitoring solutions.

The information needed to assess water quality is mostly related to its physical status (e.g. temperature), certain chemical compounds (such as heavy metals and organic pollutants), and the biological status, where bacteria contamination is an important factor. Laboratory analyses can obtain these results through various accredited techniques and enables the overall manual assessment of the water quality status. However, in recent years, sensor technologies and the evolution of wireless solutions for water quality monitoring has evolved rapidly, making it possible to integrate and deploy online monitoring solutions [16]. Technologies used can be cloud based or with local server capacity and utilize different connectivity options such as cellular and long or short-range capillary networks.

Several companies have developed commercial solutions for digital water monitoring solutions, such as YSI, Hach and Libelium where the core business for most of these is sensor development where a wide range of sensors measuring different parameters are offered. Some manufacturers also offer comprehensive solutions for data and connectivity management, but we have not found any commercial offerings related to massive IoT use cases for water monitoring at large scale. Further, to be able to deploy massive IoT networks with hundreds of sensing devices, the cost of each individual sensor device need to be as low as possible for the solution to be financially and commercially viable. In practice it means that only simple parameters can be measured, such as temperature, conductivity, pH and dissolved oxygen, since advanced sensors measuring for example compounds are too costly.

ICT companies, such as Nokia, Microsoft and Huawei are investigating how water quality monitoring can be utilized and fit into their IoT offerings for smart sustainable cities. However, to our knowledge, no major ICT company has any comprehensive offering as of today. During 2016, Ericsson initiated a project to develop a comprehensive cloud-based water quality monitoring solution, based on a massive IoT approach. The project, developed in Stockholm, Sweden, was based on a previous proof-of-concept in the US [17] and is a collaboration between Ericsson, the city of Stockholm, academia and other companies in the Stockholm region [18].

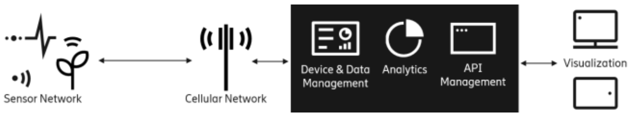

Fig. 3 – Technical architecture of a typical digital real-time environmental monitoring solution.

The goal of the project, which is still ongoing, has been to to develop a comprehensive IoT-based digital water monitoring solution. Based on the first phase that was finalized in 2017, a commercial solution was launched during 2018 covering water and air quality as well as noise measurements for smart cities [19]. During the first phase of the project, sensors were deployed in Lake Mälaren, in Stockholm, measuring different basic parameters (pH, temperature, conductivity, dissolved oxygen and redox potential). The sensors were communicating over the LTE network with Ericsson's cloud-based IoT platform (see Fig. 3).

Lessons learned from this first phase was that there is a discrepancy between sensor data and reality. In practice this means that it is very difficult for an end user to understand and interpret sensor parameter data and evaluate if there are any changes in the water quality induced by pollution or contamination. Hence, the next phase of the project will be to utilize multivariate analysis and artificial intelligence (AI) to understand the water quality parameters and identify potential pollution and pathogenic contamination of the entire water supply of a city.

The goal is to develop a solution for easy interpretation of sensor data, where changes in water quality can be observed and potential causes of these changes are suggested by the system. One example could be the indication of algae bloom, where the individual sensor parameters show an increased temperature and conductivity together with lowered oxygen content in the water. The introduction of such AI functionalities will be a differentiator compared with exisitng solutions, and take digitalized water quality monitoring to a new level. This final phase was initiated during the spring of 2018 and will concentrate on water contamination models, development of algorithms for the AI functionality and integration to a comprehensive product for smart cities.

4. DISCUSSION

4.1 The benefits and challenges of environmental data

As the previous section showed, there is a strong focus on developing solutions for environmental monitoring in general and water quality monitoring specifically, but how should these solutions be used? The following section will elaborate on the benefits as well as the challenges for digital environmental monitoring solutions. Furthermore, a number of obstacles need to be solved to fully take advantage of these technologies.

Ericsson is expecting that ICT will be a driver for enabling the potential of the smart sustainable cities of the future, and to accelerate the achievement of the SDGs [20]. IoT, 5G and artificial intelligence will potentially be powerful enablers [21] and digitalized real-time environmental data can be efficient tools for urban planning and management in the sustainable cities of the future. Urban city data can be collected from various sources, such as traffic, homes, buildings, air quality and water quality as well as weather data in general and rain data specifically. Individually, all these systems provide valuable data for the city planner and the citizens, but the true value of such data is obtained when all the systems work together combining the aggregated data.

4.1.1 ICT as an enabler of environmental monitoring

Digital environmental monitoring, such as rain monitoring and water quality solutions, is a powerful tool to understand how we affect, as well as how we are affected by the environment, and how any negative impacts can be efficiently mitigated.

To measure and understand rainfall with high detail and high time resolution with microwave assisted data, as presented in Section 2, can give valuable insights for future forecasting and flow calculations in cities, especially when climate change is expected to change rainfall patterns in some parts of the world. Better detection and predictions of rainfall can thus lead to early mitigation efforts to hinder flooding, such as investments in efficient storm water systems, but also to be able to alert citizens at an early stage of a potential flooding event. Further interesting applications and use cases are towards the insurance industry, where a need for detailed rain patterns are desired to be able to develop risk schemes and insurance policies.

However, the most versatile and interesting use for digital rain measurements through microwave links could be in emerging markets, where accurate and reliable weather monitoring solutions are scarce. Today, most weather radars are located in industrialized countries, where most emerging markets rely only on monitoring by manual gauges. An indication of the worldwide weather radar coverage can be seen in Fig. 4 from the World Meteorological Organization (WMO) radar database [22]. It can be seen that many parts of the world completely lack radar coverage.

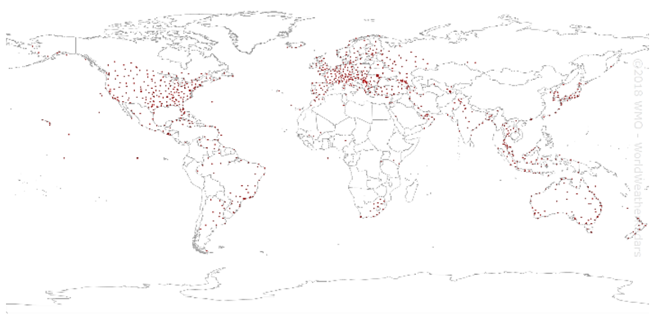

Fig. 4 – Worldwide radar coverage (WMO radar database)

The total amount of microwave links and radios globally are around 10 million, deployed both in industrialized as well as emerging markets. Hence, there is both a need and an opportunity for digital rain data for many parts of the world, where microwave links could be an alternative to weather radars as well as to serve regions where today there are no weather radars at all. The deployment of such a system would be fairly cost efficient compared with the introduction of weather radars, since only a software update is needed in the operator networks.

Later on, with the introduction of detailed rain monitoring in many emerging markets, new services and solutions can be introduced. One such solution can be micro-insurances for farmers where rain data is vital to calculate insurance rates as well as insurance pay outs. Another service is malaria prevention, since there is a correlation between heavy rainfall and malaria outbreaks [23]; timely mitigation efforts such as pesticide spraying, could be introduced after detected heavy rainfalls in malaria infested areas.

In the same way, sensor-based, real-time water quality data can be used by cities to identify potential pollution or pathogenic contamination in rivers, lakes and water sources. Digital water monitoring can thus minimize the amount of manual sampling needed and direct sampling to potentially polluted water areas. Furthermore, through the introduction of AI functionalities, pollution movements and diffusion in water areas could be monitored, and potentially traced back to their sources. The availability of long-term water quality data on a massive scale can be a tool to monitor the overall health of our water sources as well as potentially report such data to authorities.

Another aspect of pollution detection in water is the monitoring of fresh water distribution systems, where pathogenic pollutants can be detected using novel sensing technologies for bacteria detection [24]. The combination of novel sensor solutions with traditional physical and chemical sensor systems can thus enable a powerful use of IoT for water quality monitoring solutions.

Finally, by integrating solutions such as real-time rain detection and water quality monitoring, with other smart city solutions, such as real-time traffic and connected transport systems, a comprehensive tool for the smart city could be developed. As an example, detection of heavy rains would be facilitated, where any potential flooding of streets could be monitored and projected. Hence, any traffic in the area could be warned and directed to alternative routings, avoiding congestion problems and any potential material damages and risks to human life. Furthermore, by being able to monitor traffic as well as water pollution, any correlation between traffic and water contamination can be detected. In the long run, where large amounts of data are available for forecasting, such solutions and systems could then be used as large-scale planning tools for urban development.

4.1.2 Challenges and needs for digital monitoring and resilience solutions

Previously, in sections 2 and 3, two projects were shown where Ericsson is participating in the development of real-time environmental monitoring solutions. These projects provided insights on the potential benefits of using digitalized and sensor-based environmental data, where better spatial and temporal resolution in measuring rainfall through microwave links were obtained. Additionally, the different connected urban water projects have taught us valuable insights in city priorities and needs, where pollution detection and tracking as well as a need for increased spatial coverage are high on their wish lists.

For future research and development, there are some challenges that need to be addressed, of both technical and organizational nature. The first challenge is related to the sensor market for water quality monitoring. Our experience, based on the projects we are involved in, shows that there are very few manufacturers offering sensors that are suitable for massive IoT deployments. Either the price is too high, resulting in a non-realistic financial scenario to cover an entire city, or the quality is inferior, resulting in high service and maintenance costs. However, indications show that many sensor manufacturers are investing in the future of IoT, to be able to deliver low cost, highly reliable sensors. This is, however, a couple of years ahead in the future. Additionally, to be able to rely on the sensor data, and utilize it as a part of the monitoring processes of a city, sensors need to be accredited in order to report digital data to national and federal authorities. Furthermore, the sensor data needs to be easily interpretable to understand the changes in water quality. Here, the development of AI systems can be a major contributor, as described under Section 3.

The second challenge refers to organizational and process-related limitations in public organizations. Many of these digital data solutions can only achieve their full potential if proper processes to be able to utilize the data and the insights are implemented in the city as well as the data obtained being utilized in a way where informed decisions are taken continuously based on the data. Different departments within the public organization need to streamline their processes to be able to take advantage of the data received in real time. Additionally, data and IoT platforms need to be cross-functional, for the organization to be able to integrate data from multiple sources.

5. CONCLUSIONS

The technical development of environmental monitoring and smart city solutions is only one of the aspects to consider when talking about the smart sustainable cities of the future. Equally important is the ability to integrate these solutions and the data generated, as well as developing cross-functional processes for information flow within the cities to be able to make any sensible use of this information.

Solutions for digital environmental monitoring can provide data and information for environmental mitigation and climate resilience, but also be used for other use cases as shown in this paper. We have described two projects where Ericsson is involved, utilizing ICT and sensor technologies to develop such smart city solutions, where the technical aspects of the development are of importance. However, equally important is the actual integration and deployment of such solutions in cities, where the data needs to be utilized in an efficient way to fully achieve their potential. This includes the development of processes and investment in cross-functional data and IoT platforms. However, as shown with the examples in previous sections, digital real-time data provides an interesting opportunity for the smart sustainable city, as well as for the monitoring and achievement of the Sustainable Development Goals.

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