Opportunities and Challenges of Wireless Sensor Networks Using Cloud Services

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ABSTRACT

Technological advance in integrated, low-power microcontroller and wireless communication devices as well as Micro-Electro Mechanical Systems (MEMS) sensors make it viable to embed tiny networked objects deeply into the physical world. The unique characteristics of Wireless Sensor Networks (WSNs) make them attractive for application to a variety of challenging problems, e.g., the global energy crisis, climate change and population ageing. As WSNs become ubiquitous, the technology itself gives rise to some technical challenges to which Cloud Computing may offer solutions. In this position paper, we try to establish what WSNs and Cloud Computing mean from a practical perspective, and how they can help us achieve various objectives, e.g., to monitor civil infrastructure or public health, by building a new computing, communication, and management system architecture for sensing, processing, and storing physical data. In addition, we present the opportunities and challenges of jointly applying WSN and Cloud Computing technologies. Hopefully, this can help researchers realise the potential gains available from the combination of WSN and Cloud Computing.

Categories and Subject Descriptors

A [**General Literature**]: Introductory and Survey; H.4 [**Information Systems Applications**]: General; J [**Computer Applications**]: Miscellaneous

General Terms

Design, Human Factors, Legal Aspects, Management, Performance, Reliability, Security, Standardisation.

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Keywords

Wireless Sensor Networks, Internet of Things, Cloud Computing, Energy Crisis, Smart Infrastructure, IPv6.

1. INTRODUCTION

We are currently observing and experiencing the historical transition in which the analog world is transforming into its digital counterpart. The Internet has driven significant changes in all consumer industries, including books, music, shopping and communication between human beings. Today people use Facebook to keep connected with friends as a social utility, LinkedIn to build up their own professional network, chatter for real-time communications and to access news real-time through a myriad of devices, for example, iPad running iOS and Android based devices [6].

Now we have a more ambitious goal than ever before to build a smarter, greener planet [12] in which every piece of information around us can be sampled, collected, transmitted, and analysed in order to provide us with solutions to various problems, such as the energy crisis, safety issues, health improvement, and life comfort. The basic premise is the access to real-time information concerning the environments around us.

2. WIRELESS SENSOR NETWORKS

The Internet of Things (IoT) is a concept that was originally proposed in 1999 by Kevin Ashton [22] and was the first to consider how the previously outlined goal could be achieved. The WSN technology emerged soon after as one of its incarnations. A WSN is a collection of self-contained devices often utilising MEMS based sensors. These nodes are colloquially referred to as motes and we note that mote is a commonly used name in MEMS sensor literature [15]. Each mote contains a computational unit (e.g., microcontroller), a memory unit for data and program storage (e.g., Static Random Access Memory (SRAM)), Electrically Erasable Programmable Read-Only Memory (EEPROM), and flash), an integrated low-power radio (e.g., transceiver) and a power supply (e.g., batteries). Sensor nodes can

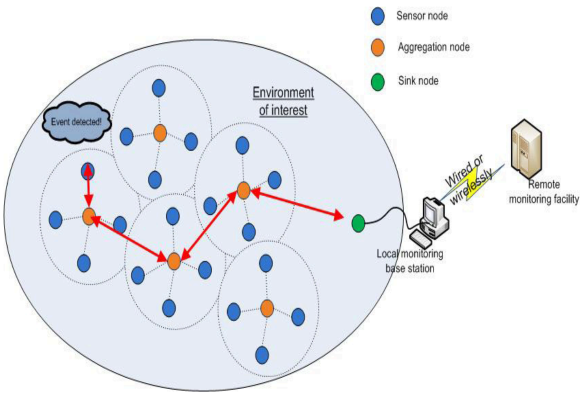

Figure 1: An example of WSNs.

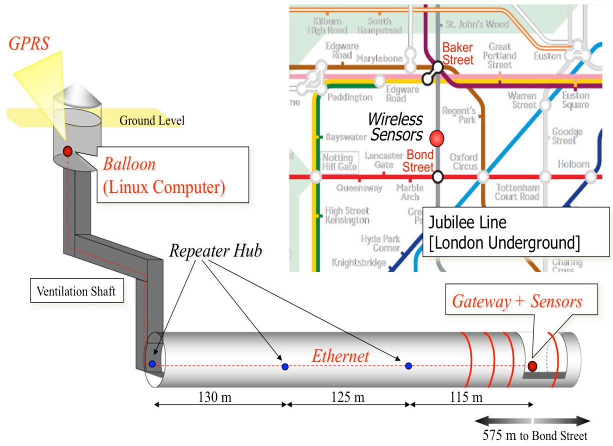

Figure 2: Tunnel monitoring using WSNs.

Figure 3: Applications of WSNs.

be deeply embedded in the physical world and spread throughout our environment, e.g., like smart dust [11], to spatially and temporally sample physical phenomena, such as temperature, humidity, light, inclination, acceleration, chemical substance, physiological measurements and environmental change. This data is then either stored temporarily in local nodes or wirelessly transmitted immediately to the network gateway/sink, as is shown in Figure 1. Then the clients can retrieve the data from the sink either using a wired or wireless link.

The actual deployment of WSNs to monitor ageing civil infrastructure in order to assess its condition is displayed in Figure 2. We have deployed a WSN in the section of a London Tube line between Baker Street Station and Bond Street Station to sense a number of physical parameters of the tunnel environment and its structure, i.e., temperature, humidity, crack displacement, and inclination. It is hoped to observe how changes in the environment could affect the tunnel deformation as a function of time [5] in a real-time manner, so that in the future infrastructure can become smart/intelligent by having sensor nodes embedded within it.

This new network of physical objects can deliver applications that create value for consumers and business alike. The nature of millimetre-scale, nonintrusive, low power, self-organising, and cost efficient WSN is showing itself to be the best option for sourcing data from the physical infrastructure around us. Moreover, this will lead to a reduced usage of resources, lowered installation and maintenance cost, and rapid service upgrade. Figure 3 depicts a variety of applications of WSNs.

Ideally, we would like to have geographically isolated WSN systems applied in different scenarios to be able to communicate with each other and thus work cooperatively on demand so that a larger data set can be generated and analysed thus enabling a comprehensive study of objects that interest us, or allowing more sophisticated tasks to be accomplished. These required interconnections between different WSNs can be enabled by making use of Internet Protocol version 6 (IPv6) [7]. To this end, a working group of TinyOS [14], which is a popular Operating System for WSNs, has released an IPv6 stack known as Berkeley Low power IP (BLIP) [13]. In addition IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) will enable a unique IPv6 address to be assigned to each of billions of sensor nodes. Therefore, addressing sensors becomes more straightforward, enabling the IoT concept to become tangible to both researchers and consumers. It has been predicted that the IoT will expand to encompass around 16 billion devices by 2020 [21]. These Internet-enabled devices can be hooked up to a network to communicate with other web-enabled gadgets and services using IPv6.

3. CLOUD COMPUTING

In contrast to the publically funded Grid Computing initiative, Cloud Computing has since its conception been driven by commercial organisations. As the concept of Cloud Computing technology has emerged as a very hot topic in both academia and consumer markets, the question of what the Cloud actually means to us needs to be answered first. It is unfortunate that Clouds as yet do not have a clear and complete definition in the literature [23]. Vaquero et al. proposed a more comprehensive definition after extracting and summarising more than 20 experts' definitions of the Cloud [8], specifically "*Clouds are a large pool of easily usable and accessible virtualised resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilisation. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customised Service Level Agreements (SLAs)*". In other words, Cloud Computing is a style of computing in which dynamically scalable resources are provided virtually to clients as a service via the Internet.

The definition and the practical deployment of the Cloud require it to have the following key characteristics:

- *Virtualisation*: Virtualisation can hide a variety of different types of infrastructure, system platforms, and data at the back-end from clients for seamless context switching and operation without worrying about the underlying hardware implementation.
- *Scalability*: The Cloud needs to dynamically resize the virtual resources if the number of services required is increased or decreased in order to achieve optimum usage while minimising resource waste or service outage.
- *Usability*: A user-friendly interface to Cloud services is desirable for each user. Because Cloud Computing is envisioned to serve clients across different fields, from academia to industry, from business to government, the user interface needs to be as simple as web browsing.
- *Reliability*: As clients gradually start moving their application and operation of computing services into the Cloud, people will come to rely more heavily on the private and centrally managed Cloud services than ever before. Providing the resilience to single or multiple data centre failures is indispensable.
- *Security*: Sensitive data, e.g., customer information, breaches are undesirable, and virtualisation enables each user to have unique access to its individual virtualised environment having a complete level of isolation.
- *Cost*: Because Cloud Computing has been driven mainly by business use, it needs to have a business model based on charging clients for using the services. Consequently, cloud service providers usually adopt some form of pay-as-you-go model.

The services of Cloud Computing are broadly divided into the following three major categories and a stack of these services is shown in Figure 4:

- Infrastructure as a Service (IaaS): Service providers provide virtualisation of computing resources (physical processing and storage capability) for hosting clients chosen platforms. One example of IaaS is Amazon Elastic Compute Cloud (EC2) [2].
- Platform as a Service (PaaS): Platforms are built upon infrastructure. This service provides development environments (e.g., Windows and various versions of Linux), programming platforms (e.g., Java VM, Python, and .Net) and APIs for building cloud-based applications and services. Examples include Google App Engine [9], Amazon Simple Storage Service (S3) [3], Azure Storage [16], and Force.com [18].
- Service as a Service (SaaS): Instead of running applications on local personal PCs, applications are exposed as a service running in a cloud platform on top of the underlying infrastructure. Consequently, such services are delivered through various types of interface, e.g., web browsers and command line terminal. Examples of SaaS are Sales Cloud 2 [19], Service Cloud [20] from saleforce.com in which Customer Relationship Management (CRM) package is provided, Google Docs programs (e.g., word processing, spreadsheet, and PowerPoint-like presentation tools) [10], and Microsoft Office Web Apps [17]. In addition, Adobe has also released their cloud version of the image editing software Photoshop Express online apps [1].

4. OPPORTUNITIES FOR WSNS TO TAKE THE BENEFITS OF CLOUD COMPUTING

The promising applications of WSNs that we have identified so far have raised a few new problems. The amount of data being generated and gathered by WSNs will increase exponentially as the number of sensor nodes rises in the near future. Even with only a few WSNs, occasional *Event Bursts* could trigger a chain reaction of *Data Bursts*. This phenomenon can be observed in the application of monitoring natural disasters using WSNs. One good example of a Data Burst is owing to the earthquake and tsunami that hit Japan in March 2011. A WSN that includes seismic sensors normally monitors earth movement at infrequent intervals, e.g.,

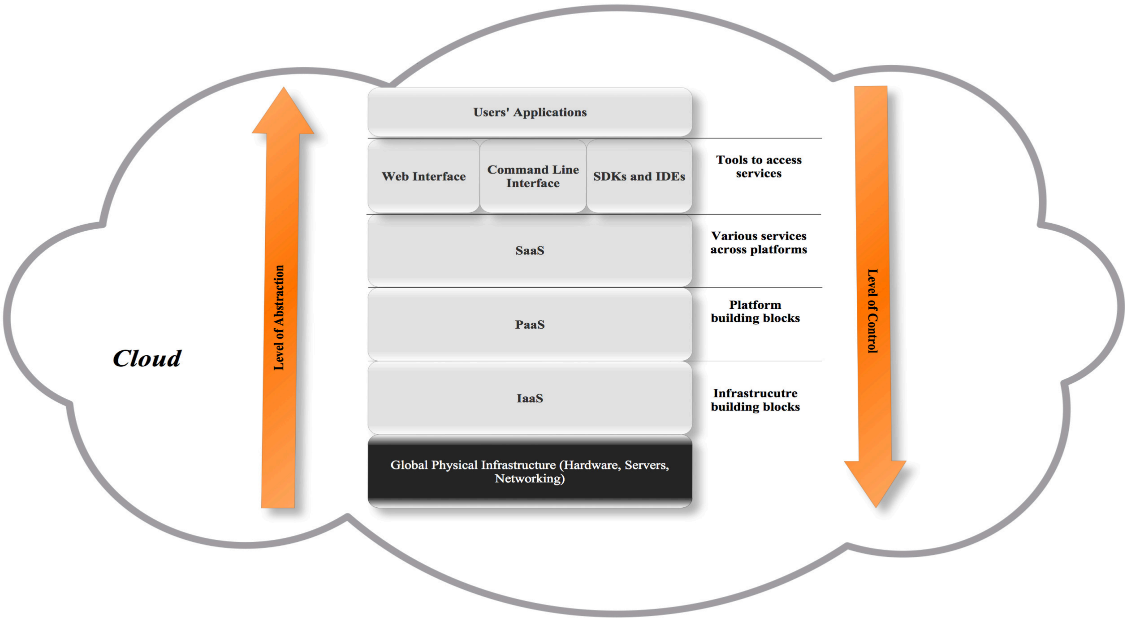

Figure 4: Service stack of Cloud Computing.

once per hour, to reduce energy consumption and storage requirements. However, the WSN will begin sampling and collecting data at a much shorter interval, say in excess of once per minute, if it detects particular events, such as movement of the earth surface or a rise of sea level. The frequency of sampling and data transfer rate can rise further if the situation becomes worse. This instantaneous peak in the data sampling and collecting process will result in what are known as *Event Bursts* and *Data Bursts*.

These phenomena could also happen in the situation where the condition of patients being monitored gets worse and there is a great possibility of Data Avalanche. That said we do not wish to lose data in these critical situations. Therefore, it is not uncommon to measure data volume in the order of exa- (10^{18}) bytes, especially in the era of eScience or eHealth. In addition, we have observed a few difficulties when undertaking real deployments of WSNs:

- *Storage*: Often a single standard PC server with moderate storage size is left running remotely in an insecure location, e.g., inside a standard office room at a company. It will be highly likely to reach the storage limit very quickly if used for long term monitoring. This has been observed when the authors worked in a project with an industrial partner, namely AquaMW LLP [4]. In this application wireless sensors have been applied on industrial plant sites in order to provide SMART solutions for seamlessly connecting the physical and digital worlds and improving efficiency and reducing energy consumption and CO_2 emissions. In the mission critical tasks in which the health of the water pump motors is tracked, it is necessary to sample data once every few seconds, e.g., say 5 seconds. There are 4 different types of sensors, i.e., energy meter, flow sensor, pressure sensor, and temperature sensor, integrated onto each wireless node. Each analog channel requires 12-bit resolution, so there are 60 bytes of information including meta data in each packet that is generated by a single node. Therefore, the total volume of data generated by a single node for a year will amount to some 0.4 GB. The deployment of WSNs for industrial applications normally involves hundreds of nodes in one network, so the total quantity of data can easily reach several hundreds of GB per year. It is clear that a conventional data storage strategy will quickly become ineffective. Consequently, data loss is very likely in such situations if timely elastic data storage mechanism are not available. In addition, automated efficient processes to build databases for several WSNs running at the same time are lacking. Therefore, developers are required to repeatedly and manually build a database for every newly setup WSN even though most of the table attributes are common.

- *Accessibility*: The actual data created from the monitoring of critical civil infrastructure, e.g., railway underground tunnels, is extremely sensitive, so there is a tight restriction on the different levels of data access to the server from the external environment. For instance, infrastructure owners should have highest privilege to access the data in comparison with other users who have reduced basic access. Currently, this is often not implemented or poorly implemented on standalone server machines. This is mainly due to unfamiliarity and the difficulty of configuration.

- *Reliability*: Because there is only one server in operation at any time, it is not resilient to single point of failure problems owing to either hardware breakdown or software crash, e.g., hacker attack.
- *Real-time Processing*: The data gathered from the site is often stored and processed off-line. There are no real-time signal processing or continuously-running algorithms for analysing data. Therefore, a timely alert cannot be sent out to end users when unusual events occur.

Current technology is not able to provide sufficient data storage and the powerful analytics capability required within a reasonable response time, and having widespread accessibility. It is probable that satisfying such requirements is beyond the scope of most small/ medium companies and academic research teams.

Such hurdles to the success of WSNs (or IoT) lead us to believe that a Cloud based computing service may offer a solution to such stringent requirements. The scalable computing capability for data processing, agile application development tools and a virtually infinite capacity for data storage make cloud computing technically compelling. Let's imagine, if wireless sensor nodes are sensing the micro-scale physical world individually, they can eventually function as the macro-probe to our world with a powerful brain when they work together in an intelligent and collaborative way using the Cloud as the backend infrastructure for data storage and processing. The Cloud also acts as a central library with expandable capacity in which developers and users only need to spend their efforts in developing the application features while other components such as security, scalability and shared data models have already been developed and tested with millions of users. Furthermore, geographically distributed data centres assure us of data safety by scheduling regular data backup to a different data centre. An overview of opportunities in the applications of WSNs using Cloud is shown in Figure 5.

5. CHALLENGES OF UTILISING WSNS AND CLOUD COMPUTING

The Cloud brings us many opportunities to deploy WSNs in various applications with the aim to resolve a number of difficult problems, e.g., the global energy crisis, by optimising resource usage and reducing carbon emissions. It enables users to easily collect, access, process, visualise, archive, share and search large amounts of sensor data from different applications. However, the synergy between these two innovative technologies exhibits some challenges that require answers in order to move both forwards:

- *Data Format and Event Processing*: There is still a lack of standard representation of data coming from different types of WSNs. The different data abstraction models supported by diverse vendors become barriers to the effective exchange of information and their retrieval. In the ideal case, the scalable API's and adaptive data structure models should make the parsing and processing data easy and user friendly. However, the data format and process is not forced to comply with a standard, so users tend to choose their favourite language or models to accomplish the job.

  For instance, one user may use Python to collect the data represented in an XML file, but the PaaS to which this user is tied may only support a development environment written in Ruby. A multi-tenant data architecture ensures data scalability, but the consistency is not 100% guaranteed when clients switch from one service provider to another.
- *Complex Event Query*: Large real-time data feeds from heterogeneous sensors could require the design of new Database mechanisms and query methods, e.g., NoSQL, for efficient and transparent data query and retrieval, instead of using classical Relational Database Management Systems (RDBMSes), e.g., MySQL and Oracle RDBMS.
- *Network Bandwidth*: As the number of sensor nodes dramatically increases and with certain latency critical applications (e.g., streaming video, voice and images with real-time multimedia content), it is a challenge to accurately transfer such a huge volume of data in a timely manner using conventional networks, e.g., mobile, WLAN, MAN, and ADSL, in which the transmission is assumed to be asymmetrical for the uplink and downlink.
- *Maintenance Dilemma*: The Cloud cannot afford a service failure because service providers need to keep their customers' loyalty. Therefore, they have implemented redundancy techniques and regular maintenance to ensure their service keeps running 24 hours, 7 days a week. This can be done by distributing their multiple data centres geographically across the world, and backing up the data regularly. The challenge is the efficient allocation

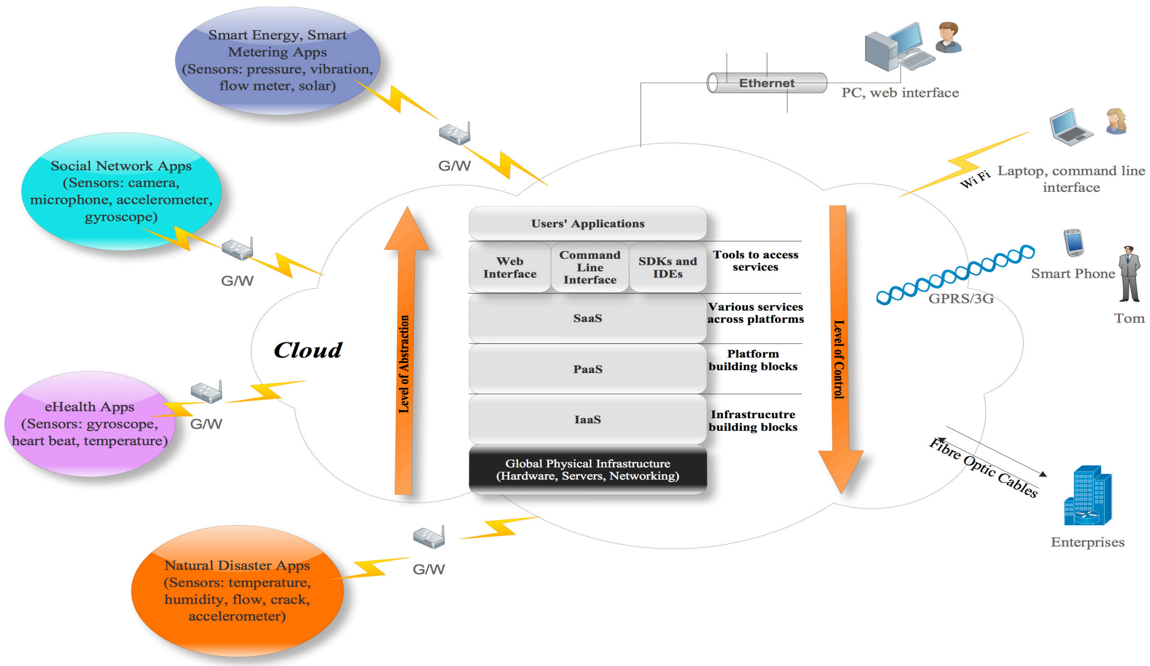

Figure 5: WSNs using Cloud Computing.

of computational resource (load balance) and storage. Furthermore, data migration becomes a serious problem.

- *Payment for Services*: The method of billing customers is not standardised and in general is not regulated. One of the objectives of introducing Cloud Computing to the market is to bring the cost of computing resource down significantly for clients. However, it becomes very difficult for customers to analyse or judge if the service they rent is over billed. Frequently, they are even confused by the way they are billed. This will increase the barrier for new users coming into the Cloud, or risk losing current customers because of poor tariff plans.

6. CONCLUSIONS

WSNs appear to be a promising realisation of the IoT. It is also believed that the synergy between WSN and Cloud Computing will offer a potential solution to various social, environmental, public problems, e.g., the global energy crisis, population ageing, and security surveillance. In this paper, we have identified the unique characteristics of WSN and Cloud Computing. This helps us to clear up some of the confusion over these buzz words, which in turn permits us to reveal the opportunities of applying one technology by leveraging another to tackle even more complex problems. We have also identified a number of challenges that we are facing, and we hope this can inspire researchers to investigate the potentially powerful combination of WSN and Cloud Computing.

7. ACKNOWLEDGMENTS

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