Remote IoT teaching across the North-Atlantic

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***Abstract*— The ability to offer courses over the Internet between remote teacher(s) and students enhances curricula and can improve quality in university work regarding both teaching and research. This is particularly true for small universities that struggle to offer comprehensive curricula due to lack of professors and students. In the spring semester of 2021, the University of Iceland offered a course on the Internet of Things taught by a professor emeritus in Atlanta, Georgia, assisted by a local professor. The lectures were given on Zoom and all assignments and exams were given over the Internet. In this paper, this course's framework will be described, how it was implemented and what was accomplished. The authors will also share their thoughts on the future of this kind of university work that has to some extent developed due to the Covid situation.**

Keywords*— *Remote teaching, Inter-continent teaching, Internet of Things

I. Introduction

The Covid-19 pandemic has greatly stimulated the use of video conferencing facilities in various aspects of society, including teaching and learning. Video conferencing has been available in various forms since before 2000 and user-friendly conferencing systems communicating over the Internet have been around for more than 10 years. This did however not suffice for video conferencing technology to gain widespread usage despite obvious advantages, including less travel, time, and money savings. During the initial phases of the pandemic, people did not hesitate to utilize video conferencing to carry on their work and to limit the pandemic's impact on their lives. The systems in place were advanced and user-friendly and, in many cases, already installed on people's computers. In Iceland, Internet connectivity has reached an advanced stage, where nearly all homes have a high bit-rate connection of at least 100 Mb/s, about 80% of urban homes and close to 90% of farms have fiber connection. This proved to be a great advantage for the Icelandic society during the pandemic.

The Icelandic educational system was able to quickly convert from traditional teaching to distance teaching using video conferencing. This began already in the 2020 spring semester and was fully matured in the autumn semester. This was one of the grounds for offering a new course on the Internet of Things (IoT) in the spring semester of 2021. Prof. Ian F. Akyildiz of the Georgia Institute of Technology in Atlanta had become a visiting professor at the University of Iceland. Prof. Akyildiz is one of the founding fathers of research on Wireless Sensor Networks (WSN), Machine-to-Machine communications (M2M), and the Internet of Things (IoT). He has taught this subject for a long time, and it was therefore a windfall for the University of Iceland to enjoy his engagement in this field. During the semester, Prof. Akyildiz was in Atlanta Georgia and the students were in Iceland except one who was in France. Mr. Saemundur E. Thorsteinsson served as Prof. Akyildiz's on-site teaching assistant. Students had therefore the option to meet with him in person.

II. Students and Course setup

The course was offered both for graduate and undergraduate students and it gave 6 ECTS credits. This was the first time a course on IoT with engineering viewpoint was offered at the University of Iceland. Before, a course on programming IoT devices was offered at the Computer Science department. The department of Electrical and Computer Engineering offers specializations called Electrical Engineering, Computer Engineering and Medical Engineering. IoT fits nicely into both the Electrical and Computer engineering specializations. There is no specialization in telecommunications offered but in Electrical Engineering, students are required to take a course called Telecommunications Engineering where the fundamentals are covered. This was though not a prerequisite for the IoT course.

Twelve undergraduate and nine graduate students registered. In cooperation with the University's Institute for Continuing Education, the course was also offered for practicing engineers where seven registered. Ten of the university students were computer science students, six were software engineering students, three came from the Electrical and Computer Engineering department one from mechanical engineering and one from industrial engineering.

The course was not built on a specific textbook. Lecture slides were very comprehensive, and all material appeared there with sufficient resolution so that it could be digested using the slides and lectures. All lectures were recorded and made available to the students shortly after each lecture. This setup gives the students very much flexibility, they are not obliged to attend lectures in real time and can watch them at their own convenience.

The lectures were twice a week for 75 minutes. The timing was selected so that both professors and students would have the lectures during work hours. This was at 16:40 – 17:55 in Iceland but 11:40 – 12:55 in Atlanta. A slight complication arose when the clock changed to summertime in Atlanta and the time difference reduced to four hours. Luckily, Iceland does not have summer and wintertime, which would probably

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have caused severe complications because Europe and USA do not adjust the clock on the same dates. At the end of each lecture, the audience could ask questions. Three comprehensive homework assignments constituted 30% of the final grade, two take-home exams weighed 20% each and one final take-home exam weighed 30%.

In the spring semester 2021 it was not possible to arrange on-site exams due to the pandemic. Therefore, on-line exams were conducted in the form of take-home exams. They were organized using the Canvas learning management system. The exams were opened at noon on Friday and closed on Sunday evening. Students therefore had a whole weekend to take an exam. After opening an exam, a student had 75 minutes to write the answers and thirty minutes for scanning and uploading. After 105 minutes, submission was closed. This methodology was well accepted by students and no complaints were received. A declaration of honesty was prepared where a student confirmed that the solution was done by him/her and assistance was neither received nor provided. No signs of fraud were detected. This was contrary to another course taught at the department where nearly all students were Electrical and Computer Engineering students. There, obvious fraud was detected in similar on-line exams. In the IoT course however, the students came from different departments and most of them did not have sufficient acquaintance to the others to conduct fraud.

The homework assignments were also provided through Canvas and students uploaded their solutions. Feedback was provided through Canvas. The University of Iceland introduced the Canvas system in 2019. The introduction was followed by a very comprehensive support period. The results have been encouraging, and Canvas's performance was excellent during this course.

Broadly, this course focused on achieving the following learning outcomes:

- Proficiency in both theory and applications relating to the Internet of Things and sensor networks.
- Breadth and depth in aspects relating to protocol design and system development.
- Analytical and critical thinking skills in the domain of wireless sensor networks.

Like in other courses at the School of Engineering and Natural Sciences (SENS) a teaching and course evaluation survey was conducted. Only five students participated which impacts the survey's statistical significance. The overall average grade for this course was 7.4 out of 10. SENS's average grade over all courses in the same semester was 7.7. Several questions were asked in the survey:

How do you grade the outcome of this course? The grade was 3.9 out of 5, which was the same as for SENS as a whole.

How do you evaluate the course planning? The grade was 3.65, well below SENS's of 4.0.

How do you evaluate workload in this course? The grade was 3.9 whereas SENS's grade is 3.7.

How do you evaluate teaching in this course? The grade was 4.3 whereas SENS's was 4.17.

How do you evaluate motivation in this course? The grade was 4.17 quite in line with SENS's.

The surveys contained many statements that the students were asked to identify their experience with. Examples are:

"My understanding of the subject has increased" was graded 4.4 out of 5 compared to SENS with 4.11

"My interest in this field has increased" was graded with 3.6 compared to SENS with 3.72.

"I learned much in this course" received 4 quite in line with SENS's result.

"Compared to other courses at this university, this was a difficult one" received 4.0 but SENS received 3.55.

"The course is demanding" received 4.2 but SENS courses 4.0.

Numerous other results were obtained that would require a lengthy description.

The results of the survey are both encouraging and discouraging. Most of the students did not have background in advanced networking. On-line teaching seems to demotivate students from active participation in lectures. Many of them hardly attended the live sessions but watched the recordings instead. Rather few questions were received on email or through the Canvas discussions mechanism. This demonstrates that in remote teaching, students lack the social proximity to other students and professors, obtained through on-site teaching and particularly through laboratories. This has consequences on their learning behavior.

III. Course content - Internet of Things

Internet of Things is a recent discipline within the field of telecommunications. It can be viewed as a set of objects having processing and communication capabilities, possibly with embedded sensors and appropriate software. Those objects can exchange data amongst themselves and other devices using the Internet or other communication networks [1]. WSN and M2M may be regarded as subsets of IoT, and M2M, Fig.1.

IoT belongs to a set of technologies called "frontier technologies" according to the United Nations technology and innovation report 2021 [2]. The frontier technologies are

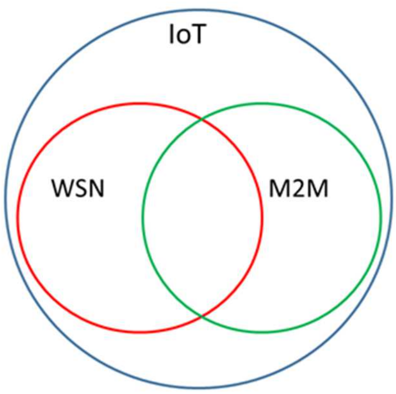

Fig.1. WSN and M2M are subsets of IoT

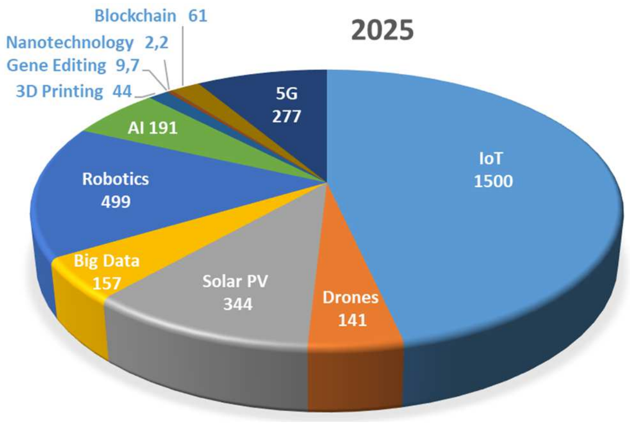

Fig.2. Market size estimates of frontier technologies in 2025 [2]

expected to grow 9-fold from 2018 to 2025 and have a market size of $3200 Billion in 2025. IoT is expected to have 47% of this market size, Fig.2. IoT has many engineering facets that seem peculiar to a person who has not been introduced to the discipline before. An example is sensor querying. A wireless sensor network can be comprised of hundreds or even thousands of sensors that must use as little energy as possible to extend battery life to a multitude of years. One of the principles of IoT is that computing is less expensive than communicating in terms of energy. Therefore, sensors are grouped according to some criteria and aggregation nodes are determined. The sensors convey their readings to the aggregation nodes that compute statistics from the sensor data, e.g., the average and standard deviation of all data from the sensors in their group. Those statistics are then conveyed higher up in the network tree and may again be averaged before ending in the data sink node. For sensor querying, a dedicated sensor query language has been devised called Sensor Query and Tasking Language (SQTL) [3].

After an introductory lecture, a review of the factors influencing sensor network design was given. Node components were reviewed including microcontrollers, memory, transducers, and transceivers. Factors such as scalability, production cost, hardware constraints, sensor network topology, operating environment, transmission media and power consumption were discussed. Detailed calculations of power consumption were reviewed and taught how to estimate energy usage of processor operations such as transmitting, receiving, or calculating. From knowing the battery capacity, calculations of this kind can help in estimating the lifetime of a node.

Due to the small size and low power of sensor nodes, conventional networking protocols used on the Internet are not suitable for IoT, e.g., http. Therefore, lightweight protocols have been developed for IoT. Two examples were introduced, MQTT (Message Query Telemetry Transport) and CoAP (Constrained Applications Protocol). MQTT presents an interface between applications and TCP/IP, whereas CoAP comes between the applications and UDP/IP. This setup is used where even smaller overhead is required than in MQTT/TCP/IP and it also enables multicasting.

Medium Access Control (MAC) is a major design issue in networking where nodes share the same medium as in WSN. Proper MAC design leads to node energy minimization. In networks with many nodes, the probability of frame collisions is high leading to increased frame loss and repetitions. Therefore, collision avoidance methods have been devised that significantly reduce collision probability but increase latency. A high number of MAC protocols have been developed to address those challenges in WSN.

Conventional network routing cannot be applied on sensor networks. The sensor nodes do not possess IP addresses, they are content based and data centric. Therefore, routing protocols appear that fall into three categories, data centric protocols (e.g., flooding, gossiping, SPIN, rumor routing etc.), hierarchical protocols (e.g., LEACH, PEGASIS, TEEN), and location-based protocols (MECN, SMECN, GAF, GEAR).

Many communications technologies were introduced in the lectures. This includes Personal Area Networks (PAN), Low Power Wide Area Networks (LPWAN) and cellular networks from 2G to 5G. Among PAN technologies are the IEEE 802.15 based Bluetooth and ZigBee, and 6LowPAN that is used to integrate WSN into IPv6 based Internet. Associated with 6LowPAN is the Routing Protocol for Low Power and Lossy Networks (RPL, “Ripple”) that is powerful for routing in sensor networks. In the LPWAN LoRa, LoRaWAN and Sigfox technologies were introduced. This was followed by an extensive treatment of the use of cellular systems for IoT, using the 2G based Extended Coverage GSM (EC-GSM-IoT), the 4G based LTE-M and NB-IoT. The treatment on cellular system usage for IoT was concluded with an extensive chapter on 5G based IoT [4]. From the beginning of cellular networks, the research community has started preparations for the next generation when deployment is starting for a new generation. The situation is no different at the beginning of 5G. Research has already commenced for the 6^{th} generation of cellular mobile communication systems that will probably be introduced early in the fourth decade of this century [5].

There are many technologies that support the Internet of Things. Examples are middleware systems for IoT such as Microsoft Azure, Oracle Cloud, Cisco IoT cloud and IBM Watson IoT to name a few. Furthermore, machine learning technologies play an increasing role in IoT. Those are used for applications such as pattern recognition, anomaly detection and even prediction. Localization and positioning technologies play a role in IoT. GNSS (Global Navigation Satellite Systems) are important position sensors in areas having a free sight to the sky, but do not work indoors, underwater, or underground. Then, other ranging technologies must be applied, or methods based on received signal strength.

Internet of underwater things is currently a hot research topic. Attenuation underwater of far-field electromagnetic waves is extremely high, yielding them impractical for communications. Magnetic induction communications have a lower attenuation and present a possible solution, at least where there is not demand for long ranges [6]. Acoustic signals are much less attenuated underwater then those built on electromagnetics, but they suffer from low bit rates.

Internet of underground things is also a very interesting research topic and offers a range of useful applications. This topic includes communications in soil, mines, and tunnels. Applications include toxic substance monitoring near wells, earthquake and landslide prediction and monitoring, soil condition monitoring on golf courses or football pitches, or for precision agriculture to name only a few. As in many scenarios, wired underground networks are impractical and wireless networks are preferred. Connectivity over electromagnetic waves is the only practical solution. Here, both communications using far-field electromagnetic waves as well as magnetic induction are possible. The attenuation is extreme for both cases, but an exciting option is to use so-called magnetic inductive waveguides [7].

Although the IoT field already described is very extensive, there is a range of new research and technologies for IoT on the horizon. One aspect is the Internet of Space Things (IoST) described in [8]. IoST opens possibilities for many new services that can be provided on a global scale. Examples are Internet provisioning to under-served or disrupted regions, and intelligent global transport management.

IoT technology does not only reach space dimensions but is also present in nanoscales. This is called the Internet of Nano-Things [9] and is concerned with the interconnection of nanoscale devices with existing communication networks and ultimately the Internet.

Finally, the IoT technology has also found its way into the field of biology. This presents a paradigm shift for communication and network engineering. Bio-NanoThings stem from biological cells and are enabled by synthetic biology. They are expected to perform functionalities such as sensing, processing, actuation and to be able to communicate with each other [10].

IV. Teaching Methodology

As described above Prof. Akyildiz gave lectures based on detailed and comprehensive lecture slides. Students were given three home-assignments that they needed to solve during the semester. The assignments were thoroughly reviewed, and feedback given. Both factual questions were asked and problems requiring calculations needed to be solved. Questions like "How is topic filtering performed in MQTT?" and "Why does CoAP support multicast but MQTT does not?" were a part of the assignments. Also, problems like "Given a sensor node that consumes 600 µA when the radio is not transmitting and 25 mA when the radio is transmitting. It is powered using two batteries in series, each with 3 V and 2200 mAh. How long do the batteries last, if the device is transmitting with a duty cycle of 20% but the battery leaks 20 mJ of its energy every hour?"

Questions and problems of this kind require the students to dive into the material and dig up the answers. This requires much work resulting in good learning.

The learning would have been positively enhanced by employing laboratory teaching. In the spring semester 2021 this was not possible due to the pandemic. Most laboratories had to be postponed or dropped, others were turned into remote laboratories miscellaneously successful.

Setting up laboratory teaching is labor intensive and must be done during a course of several years in a small university. The importance of laboratory teaching is not disputed, the reader is referred to [11] for a more detailed treatment. It is the aim to offer the IoT course with laboratory teaching if it will continue to be offered.

V. The future of remote teaching/learning

Experience won from this course is positive and indicates that teaching over very long distances is practical and successful. It is though preferable that time difference allows people at both ends to convene during working hours. This success assumes of course that all prerequisites are fulfilled such as high-quality Internet connectivity on all ends and stable conferencing software running on stable hardware using a reliable cloud storage. During the 14 weeks duration of this course, no incident occurred where a lecture was broken due to technical difficulties. Furthermore, no recording was lost, and no incident was reported that a recording could not be delivered. It would have been constructive for both professors and students to have had the opportunity to meet in person at least once during the semester. This was sadly not possible in the spring semester of 2021 when travelling was heavily restricted due to the pandemic.

A positive aspect of the pandemic is though that peoples' eyes have been opened towards the possibilities video conferencing offers for teaching/learning and other aspects of society. Given the experience gained during this course, it is highly likely that this option will be further utilized in a near future. Recordings of lectures also increase students' flexibility; they can follow lectures at any time of their convenience and at any place. This may have the consequence that demand for lecture rooms will decline in the future and university campuses may shrink. The drawbacks are in the lack of social connectedness amongst students and to professors.

VI. Conclusions

A teaching/learning experiment across the North-Atlantic was described in this paper. The course subject was a highly advanced field of technology called Internet of Things. The treatment was very comprehensive and detailed. Students worked on homework assignments and take-home exams using the Canvas learning management system. The course was successful, bringing the students a wealth of information they can use for their advantage in future jobs or studies. The success was thanks to good stable and powerful technology infrastructure, both in terms of connectivity and IT. This is a precondition for success.

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