3D Virtual laboratory for Wireless Sensor Networks

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***Abstract* — In this paper we describe how a wireless sensor network simulator was integrated into a 3D environment for use in educational environment. Simulators are very useful aid in teaching process, especially in the area of Wireless Sensor Networks. This paper also presents opportunities in engineering education, in particular in the area of wireless networks, through the usage of virtual laboratories.**

***Keywords* — 3D environments, education, visualization, wireless sensor networks.**

I. Introduction

THE overall goal of engineering education in the area of wireless networks and wireless sensor networks is to teach complex concepts of these networks, and to prepare students to deal with various constraints such as very limited energy and low processing power of these devices. In the past, the role of the student was to learn passively, to obtain knowledge through accumulation of the new information, and the role of the university was to create an environment to provide this information to students. However, in recent years, this perception of learning has evolved to consider teaching as the building up of knowledge actively, through the interaction between the university, students and resources. Some of these resources are simulation and laboratory exercises. Laboratory work is nowadays requirement in Engineering, Science and Technology education, and it is made possible thanks to technology-enhanced learning (TEL). It aims at achieving pedagogical goals. Thus, from the earliest days of their education, instructional laboratories must be an essential part of engineering programs.

The main goal is to reduce the gap between classical theoretical course and real networks. It is important to allow students to operate with devices and systems as realistic as possible. Unfortunately, installation of expensive wireless sensor network (WSN) in an academic environment is not a trivial task, even in the developed countries. The focus has been turned to virtual laboratories. Teachers can make learning materials available through Internet, to a much larger audience of students. Such virtual laboratories have become a very attractive and low cost solution.

In this paper we will present one such solution. We have created virtual laboratory, and integrated a wireless sensor network simulator in it. 3D environment offers great possibilities for visualization of wireless sensor networks, and together with the simulator which offers simulation of various algorithms; we aim to visualize complex abstract algorithms in virtual 3D space.

The paper is organized as follows: in Section II we present eWISENS, educational simulator which we used for simulations. Section III gives short description of OpenWonderland, 3D environment we used together with eWISENS in our simulations. In Section IV we discuss the importance of 3D environment in learning of wireless sensor networks. Section V and VI present developed case studies for the use in classroom. Finally, Section VII draws conclusions and gives possibilities for future research work.

II. eWISENS Wireless Sensor Network Simulator

Most of the wireless sensor network simulators that exist today, and which have been reviewed in [2], are intended for advanced research, and are too complex and intimidating to the students. Most of the commonly used simulators in the education fail when it comes to the simplicity of use. eWISENS [3] is a discrete event simulator built atop of JProwler simulator. It is designed for education, but can also be used for verifying and analyzing communications protocols of wireless sensor networks. It is a probabilistic simulator capable of simulating wireless distributed systems, from the application to the physical communication layer. JProwler was chosen because it can incorporate arbitrary number of nodes, on an arbitrary topology, and it was designed to provide fast and easy way to expand and prototype different protocols and applications. eWISENS is completely written in Java programming language.

eWISENS system allows a student to design and simulate a desired wireless sensor network. The design can be carried out in one of two ways. The first, self-learning way, allows the user to design various WSN scenarios on their own, and to explore WSN protocols at their own pace. The second way is focused on the laboratory exercises held on WSN course.

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eWISENS supports a variety of mathematical algorithms from the graph theory which are commonly used in describing wireless sensor networks, such as MST (Minimum Spanning Tree), UDG (Unit Disk Graph), Voronoy diagram, Relative Neighbourhood graph, Gabriel graph and graph colouring for example. It is also possible to switch to the matrix view of the graph, where students can see the adjacency matrix and Laplacian matrix of the given graph.

Furthermore, it is possible to perform full spectral analysis of the graph. Spectral graph theory plays an important role in WSN. Physical networks, such as WSN or computer networks, can be represented as graph, and it is possible to apply spectral analysis.

III. Open Wonderland

Project Wonderland is a toolkit for building 3D virtual worlds, which has been developed by Sun Microsystems Laboratories and it is fully based on 100% open source Java technology [4]. Wonderland is extensible so developers and graphic artists can extend its functionalities to create new collaborative 3D virtual worlds. It also supports a high level of communication via highly immersive audio and enables desktop application sharing, among other features. Users are represented by an avatar. Participants in a scene can hear other people present in a virtual space at high sound quality by means of a headset or microphone and speaker or by the use of a dedicated chat window for text messages. Open Wonderland easily supports multiple, simultaneous conversations within the same virtual space, since voices or other sounds become softer as you move away from them. The scene generated by an Open Wonderland client can be viewed from various perspectives (first person or several third person perspectives).

The development of the original Wonderland platform by Sun Microsystems was originally conceived as a tool to support collaborative working by Sun employees. It had several clear design goals:

- Focus on social interaction, formal and informal;
- Strong sense of social presence, allowing for discussion of various topics;
- Spontaneous, unplanned interactions, particularly socializing before and after planned events to build trust;
- Communication enhancement during formal interactions;
- Design for collaboration;
- Seamless document sharing with no need to switch contexts;
- Extreme extensibility;
- Allow developers to add any sort of new behaviour.

Therefore, the key strengths of using the Open Wonderland toolkit in education can be characterized as:

- The additional dimension (height) introduces new possibilities, and enriches the simulation. Using a 3D model enhances realism of the simulation;
- More realistic perception is provided. The purpose of this kind of interfaces is to obtain immersion systems that emulate a real environment and produce the most effective learning;
- Scalability: from very large to very small implementations (application design is modular so that it can be relatively easily extended by developing plug-ins);
- Open and extensible: 100% Java;
- Open source.

IV. Wireless Sensor Network Simulator in 3D Environment

3D environments have become common technology in the past few years due to the increasing availability of faster and robust hardware and software. Virtual laboratories, scientific visualizations, and some collaborative work approaches are just some of the successful fields of 3D graphics applications [5].

The most important term is Virtual Environment (VE), which is a computer generated spatial environment, where the stimulation of diverse human senses gives the user a feeling of being immersed. Immersion means how deep the user is emotionally involved within a specific virtual environment. A great research challenge for educational technology professionals is to build technology that not just supports the learning process, but also connect students and educators in a way so they can easily cooperate, even when both parties are geographically spread.

Our virtual 3D networking lab is implemented using free, Java-based open source toolkit Open Wonderland for creating collaborative 3D virtual worlds. The integration of eWISENS with Wonderland will not significantly change the process of creating simulations, but will provide Wonderland modules and cells that implement the eWISENS framework. These modules will provide simulation engines that run within the Wonderland environment, render engines that execute in the Wonderland client, and manage the communication between the server and clients. In Wonderland a module is similar to a plug-in, just by including the eWISENS module and specifying the top level Java simulation class, it will be in your world.

This research investigates the learning benefit for students and educators by using avatars in virtual worlds for collaboration in educational environment. We strongly believe that virtual environment plays an important role converging collaborative technologies and tools such as video, graphics and real time simulations. Such a game like design, it keeps students interested even though they are physically remote. Combined with peer cooperation, the real time visualization helps students fully understand the dynamics of the given exercise. Once the students see the same behaviour at the same time, it is easier to cooperate on misunderstood concepts. Users can explore our 3D space, analysing eWISENS simulations from different locations in the room or even in the building.

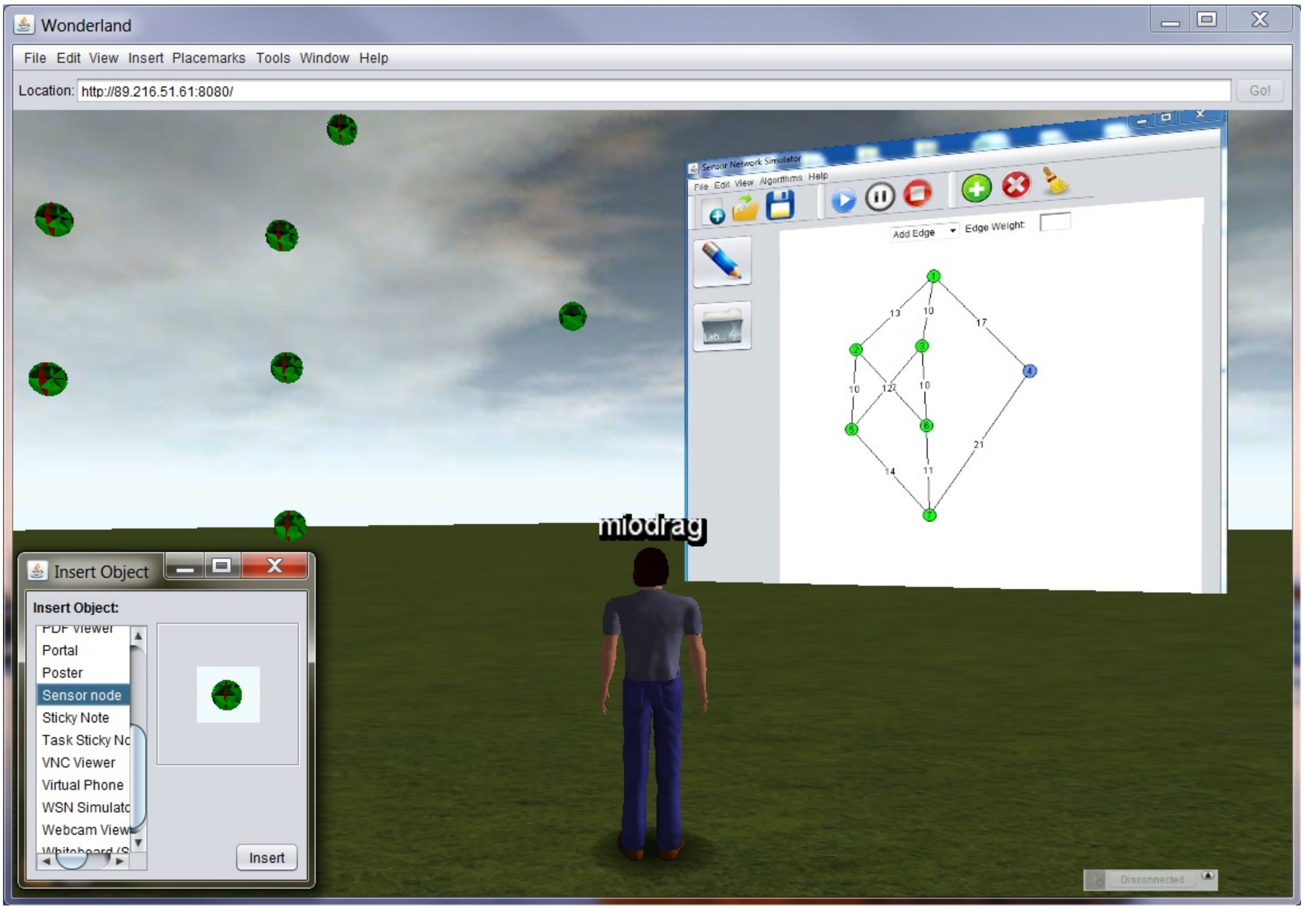

Fig. 1. Integration of eWISENS in Open Wonderland.

Moreover, the combination of a collaborative learning environment with internet-accessible sessions is a less expensive solution for educators, because both are based in open source technology and sharing of resources. Both are easy to use and are intuitive. Furthermore, students can understand complex WSN concepts much easier when they can visualize it in 3D. Some of these concepts are localization, routing and spatial mobility of the nodes.

We are also planning to evaluate the different user interfaces approach considering student's cognitive process, relevant features and entertainment. Through such a study we can polish our design and generate new guidelines.

These are the first steps integrating eWISENS simulations in our collaborative virtual learning environment. We will continue to research ways 3D environment can increase even more its pedagogical value fostering the learning process. Scientific collaboration may happen in the future primarily in virtual environment.

V. Virtual Laboratory – Case Study

WSNs are often analysed in the form of graph. One of the most common problems in WSN is routing. Routing can be affected by a numerous factors, such as network connectivity, mobility of the nodes and type of traffic through the network. Routing protocols in WSN are much more complex compared to static wired networks.

One of the simplest routing techniques is flooding. The packets are simply sent from the source to all of his neighbours, and then these neighbours send packets to all of their neighbours etc. The process continues until the packet reaches the destination. However, this method has very poor characteristics of the network throughput, as the network is congested with unnecessary packets. In case of WSN and ad hoc networks in general, better techniques of routing are required. The application of graph theory concepts in design of routing algorithms is crucial.

Spanner of the graph is such sub graph which preserves approximate distances between all pairs of nodes. For a given value t, t-spanner of graph G is such sub graph S, in which for each pair of nodes the distance in S is at most t times bigger than the distance in G. Parameter t is called multiplicative stretch factor, and S is called t-spanner of graph G. For a given graph, there can be more than one spanner. These spanners represent different paths between any two nodes. Routing algorithms use this concept, as spanners offer alternative paths and increase network throughput in case of congestion.

Proximity graphs have a major influence in topology control and connectivity of WSN. Edge between two nodes exists if these two nodes are close enough according to a defined proximity metrics. Many different proximity metrics have been defined, which leads to a large number of proximity graph types. Some of the most important proximity graphs are Unit Disk graph, Nearest Neighbour graph, Minimum Spanning tree graph, Relative Neighbourhood graph etc. In this case study we have analysed Minimum Spanning tree graph.

Minimum Spanning tree of a weighted graph G is a spanning tree of G whose edges sum to a minimum weight. In other words, a minimum spanning tree is formed from a subset of the edges in the given graph G, with two properties: it spans the graph (includes every vertex) and it is minimum, i.e. total weight of all edges is minimal. As it is possible that several edges of the graph have the same weight, it is also possible that one graph has several MST.

In the fig.1, we can see 3D sensor network, together with its two dimensional translation in eWISENS. The calculation of MST is presented in the fig.2. The edges which are included in the MST are marked red.

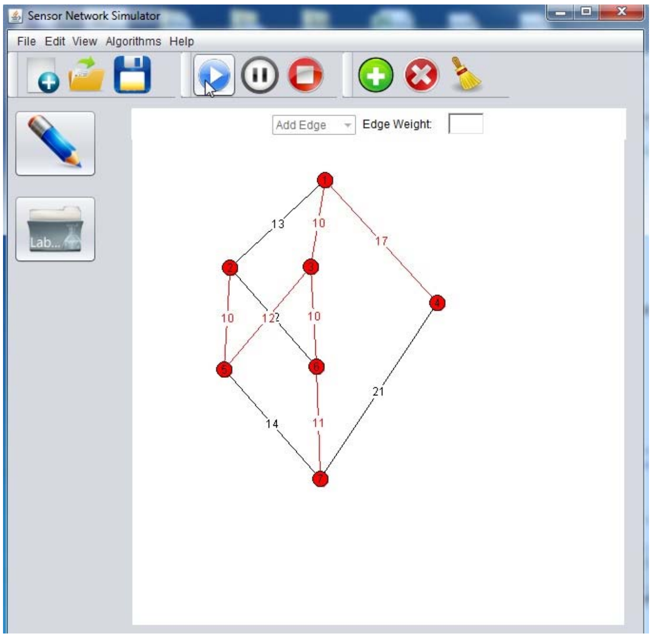

Fig. 2. Calculation of the MST in eWISENS.

MST in WSN represents an energy efficient communication path, as the cost of transmission between two nodes is proportional to the square of their mutual distance. Therefore a small change in mutual distance may change the cost of transmission significantly. Most of the energy efficient routing protocols combining data fusion and routing are based on MST or some sort of spanners in general.

VI. Spectral Analysis

The main advantage of using spectral analysis of a graph comes from the fact that the eigenvalues and eigenvectors are calculated very fast, with relatively low complexity [6]. Some of the parameters of the graph spectrum contain hidden information of the structure of the graph. Some of the eigenvalues are more important than others, and their analysis is of great interest.

The largest eigenvalue of the adjacency matrix, also known as index (or spectral radius) of the graph, is equal to dynamic mean value of vertex degree in graph. It takes into account not only immediate neighbours, but also neighbours of the neighbours etc. This value is also a measure of branching of the graph. The larger the value, the branching of the graph is greater, and the graph is better connected. The largest eigenvalue can also be used for modelling of virus propagation through the network. The smaller the largest eigenvalue, the robustness of the network against the spreading of viruses is.

It can be seen that requirements for good connectivity and robustness are contradictory. If we want greater connectivity and faster spreading of information, we would target greater value of the largest eigenvalue. However, robustness of the network would be lower and network would be more susceptible to fast spreading of viruses.

Second largest eigenvalue is related to the algebraic connectivity of the graph. Therefore, for regular graphs the problem of maximizing the algebraic connectivity becomes equivalent to that of minimizing the second largest eigenvalue [6]. Third largest eigenvalue roughly describes how difficult is to divide graph into separated parts.

The adjacency matrix for the given graph is shown in fig.3. The spectrum of the graph is shown in fig.4.

Adjacency Matrix

0	1	1	1	0	0	0
1	0	0	0	1	1	0
1	0	0	0	1	1	0
1	0	0	0	0	0	1
0	1	1	0	0	0	1
0	1	1	0	0	0	1
0	0	0	1	1	1	0

Fig. 3. Adjacency matrix of the given graph.

Block Diagonal Eigenvalue matrix

-2.732	0	0	0	0	0	0
0	-1.709	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0.732	0	0
0	0	0	0	0	0.806	0
0	0	0	0	0	0	2.903

Eigenvalues

-2.732, -1.709, 0, 0, 0.732, 0.806, 2.903

Fig. 4. Spectral analysis of the given graph.

VII. Conclusion

In this paper, we have described the integration of wireless sensor network simulator into OpenWonderland, and creation of virtual laboratory. 3D virtual labs are very important for students, especially in developing countries, as the cost of real equipment for experiments can be very high. Through Internet access, the audience can be much bigger than in real labs, thus enabling more students to visualize and understand complex concepts of WSN.

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