Wireless Sensor Network based Monitoring, Cellular Modeling and Simulations for Environment

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Wireless Sensor Networks (WSNs) can be deployed to observe physical phenomena such as pollution, flooding, insect invasion, and land degradation. Deploying wireless systems implies to match physical constraint such as point to point radio propagation, and physical sensing coverage. By building executable cell systems, we show that a number of conditions can be evaluated. An example is line of sight computation, another is wind or water propagation in complex geographic situations. This paper will explain a method to produce automatically parallel simulators that can be federated later to address the whole problem of deployment design and physical phenomena modeling and simulations.

This work is developed in an international group (SAMES) with the purpose to build and validate tools easing observation and control aimed at understanding environment evolution and risk reduction.

Keywords — Wireless sensor networks, cellular automata, physical modeling, simulation, line of sight, insect invasion, parallel algorithms.

Introduction

Good knowledge of environmental and physical phenomena will raise awareness of environmental issues that leads to better policies and better participation of citizens. Wireless Sensor Networks (WSNs) are a key technology for environmental and physical monitoring in a green smart city (OECD 2009), that will allow to a better understanding of environment.

A WSN regularly measures values representing the state of a physical system such as water levels for floods monitoring and CO2 concentration for air pollution. The collected data combined with external knowledge and data (ex. rainfall data, wind data) are then used to monitor, model and simulate the system.

Advances in technology make WSNs an attractive and cost effective proposition. This allows a possible deployment of more sensors, that means having more measurement points and better coverage. The latter increases the precision of a model and simulation.

The problems are how to manage sensor deployments to overcome physical constraints and to get better coverage? Sensor coverage reflects how well sensors can sense physical phenomena in some locations, and is one of the metrics used to measure the performance of sensor networks (Wang, B 2011).

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5SAMES stand for Stic Asia Modeling for Environment and Simulation. The actors come from University of Brest Occidental France (B.Pottier, V.Rodin, B.Nsom, L.Esclade, Raonirivo N Rakoroarijaona), CIRELA Paris (O.Goubier), IRD Paris (S.Stinckwich), Cantho University (HX Huynh, BH Lam), Hanoi (Vinh), BPPT Jakarta (Udrekh, Hafidz Muslim), DRR Foundation Indonesia (Surono).

Radio signal estimation in a city is critical due to their non flat characteristics. We cannot predetermine where signal goes and which places where signal can be received. It is known that round with a vague power estimation of signal is not enough if the surface is not flat. So it becomes important to develop tools allowing the estimation of the situation and the planning of the sensor distribution in the best way.

Our research focuses on cellular models to study both a physical phenomenon and the measures taken from a WSN on the same geographical area. The location of sensors has both an effect on the effectiveness of the monitoring where correct positions are giving adequate measurements, and the cost related to the number of sensor nodes necessary for coverage. In a WSN, we have to ensure that sensors can communicate with their neighbors. Parameters like the coverage area, the communication technology (LoRa, ZigBee, ...) and the ground contour are important in that regard.

The next section will present an overview of WSNs, followed by a short introduction to the cellular modeling and simulation. Further an example on the line of sight computation and another example on the insect invasion will be introduced including the results. And the paper will be ended by a discussion on the current and potential collaborations.

Methodology

Wireless Sensor Networks

A WSN consists of sensors, distributed in some area to measure values representing a state of a physical system. For an environment monitoring, this concerns geographically distributed measurements. Further, physical phenomena are dynamic and change with time, that means the periodicity of the measurements is also essential.

Sensors measure parameters of a physical phenomenon to be monitored. For example, water pollution in rivers and streams can be monitored, by measuring some pollutant concentration in the water. Combination of physical phenomena can be observed and simulate. Fig. 1 shows a forest fire and pollution effects of this fire on the river, where pollutants produced from forest fire can be observed using a WSN and the phenomena can be simulated (Hoang, VT, 2015).

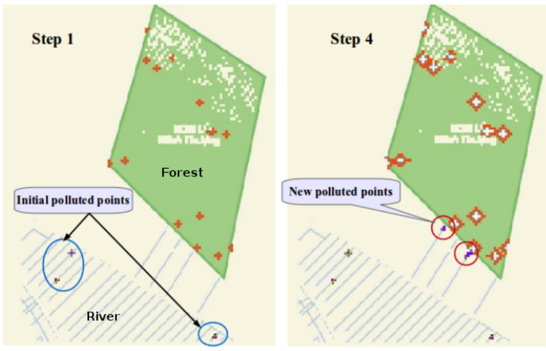

Fig. 1. Two regions marked with the red circles representing the new pollution created by the ashes, which are formed from the forest fire.

A sensor module consists of a micro-controller, a number of sensors, and a radio communication. For some applications, it’s important to consider the power consumed by a sensor module, especially if it’s outdoor and can only be powered by a battery.

Measurement data from sensors are sent to the server via networks. The latter could be in mesh, in star, or hierarchical configuration. The well known technologies such as GPRS, WiFi can be used. Currently, technologies like ZigBee, SigFox, LoRa are available for low rate, low power and low cost communication. Cellular companies are also preparing technologies and standards such as cIoT and LTE-M that allow low rate and low power communication (Nokia Networks, 2015).

The collected data are then stored in a database. A complex mathematical model can be used to analyze and forecast. For example, in the case of flood monitoring, flood forecasting is necessary to warn people in the area to reduce risks, protect property and save lives. External data sources could be needed to complete a model of a physical system, such as weather and topology data for a watershed model. Further, data can also be used to study this flood phenomena, to understand better a flood prone area. Information obtained from analysis, modeling and simulations, is then disseminated to experts, authorities and the public.

Geo-localized Cellular Modeling and Simulation

Geo-localized cellular modeling is a very suitable approach to represent a physical and environmental phenomenon, and its evolution. Important parameters of this phenomenon are measured and collected by a WSN, carefully planned, implemented and deployed in the same area as this observed phenomenon. The collective measures should cover this phenomenon, that means a cellular modeling can also be used for a WSN deployment to plan some parameters such as sensor locations, number of sensors. Further, the periodicity of the measurements is considered to follow the evolution of the observed phenomenon.

A cell in geo-localized cellular model represents the local state of a physical phenomenon. The system evolution is based on neighborhoods defining the communication between cells. There are 2 most common neighborhoods, Von Neumann and Moore (Ilachinski, A 2001). The cells follow a set of rules, applied each time step changing the state of the cells in the way the whole system evolves.

UBO/LABSTICC has developed PickCell / NetGen, a basic tool allowing the analysis of a geographical zone, in the form of geo-localized cells in 2 dimensions. The cells are defined on a browser of maps (Lam et al. 2016, Tran et al. 2016, Iqbal & Pottier 2010, Pottier et al. 2010). The cells can be completed with additional information such as elevation, weather data (GRIB), geological data and land use. The cells allow the computation of radio signals line of sight taking into account the obstacles (elevation). It also allows the prediction of possible water flow through the slope lines. Fig.2 shows a screenshot of PickCell where lattitude, longitude and elevation data are included in the system.

PickCell can generate program in Occam to be executed as parallel processes, or in CUDA to be executed on a GPU to accelerate the computation, as well as data needed for the computation. The behavior of the cells, according to the represented phenomenon, can be added to the simulation.

Some modeling and experimentation have been done, for examples, Brown Plant Hoppers and the light traps in Mekong Vietnam, as well as wind modeling. In this paper 2 examples are presented, a line of sight computation and a desert locust invasion.

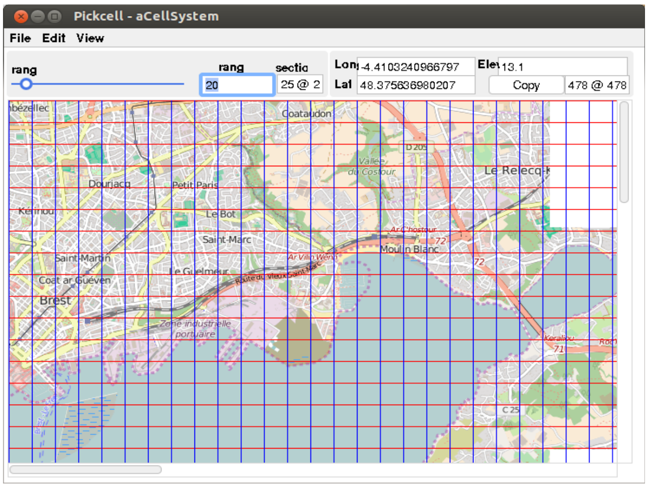

Fig. 2. A screenshot of PickCell showing a map with geo-localized cells.

Cases and Results

Line of sight computation

A good coverage of an observed phenomenon depends not only on the sensors (location, number, precision) but also on the communication technology and the deployment area. The topology of the later, landscape and land-use will constrain radio propagation.

Radio signal propagation can be described as a physical fact, or as a logical connectivity between nodes. Several approximations of this propagation can be done, as example by disk modeling coverage for a particular range, by ray tracing computations, or line of sight computations. We use this last model to summarize how the flow is working. Once *Space* is selected, a cell resolution is chosen (square of 25 by 25 pixels on Figure 2, representing 478 × 478 meters). Not shown is the synthesis of a cell system according to the execution target. We used a Von Neumann N, W, S, E neighborhood. At this stage, additional data are fetched from servers outside: we have added elevation based on each cell geographic position. Simulation programs are produced in few seconds, then they are bound to a particular behavior, compiled and executed.

When the physical space description is obtained, we are interested to compute reachable cells in line of sight from an emitting position. Line of sight represents a ray broadcast in any direction from the emitter. The ray propagation can be stopped by ground topology (hills, valley). Simulation mimics the physical behavior, by propagating the signal inside a tree rooted at the emitter cell, and covering all the *Space* in concentric circles. Each new step in the algorithm covers a new circle, and the computation finishes in 2× log n steps where n is the number of cells. During ray propagation, the ground profile is collected into routes that are completed progressively based on positions and elevations. Each cell can decide if the emitter is visible or not by comparing its elevation to the received profile.

The results of the line of sight computation are shown in the fig.3, where the cells with blue colors can communicate with the emitter.

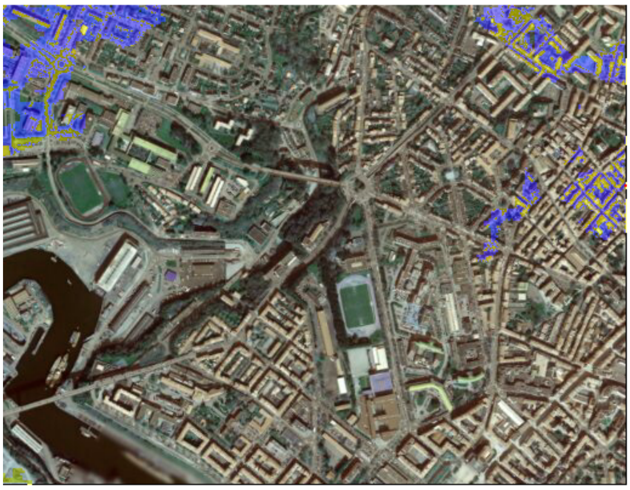

Fig. 3. Results of line of sight computation, accelerated by GPU (Table 1)

In practice, for execution, tools allocate cells on the accelerator and compute channel connectivity. The level of effective parallelism is high: common GPUs have several hundred of processors, thus the computations finish at impressive speed (see Table 1).

Resolution (pixels)	Number of cells	Execution time (ms)	
		GTX480 (480 CUDA cores)	GTX680 (1538 CUDA cores)
50	272	8.3540	7.1621
45	342	10.6850	7.8599
40	420	13.2610	9.0376
35	575	17.3560	9.8067
30	783	18.1400	10.0880
25	1155	18.3000	10.2100
20	1763	18.9860	10.6300
15	3158	19.3840	10.9990
10	7217	22.3900	22.1930
5	29044	88.5340	88.3460
3	70991	249.1000	243.6200

Table 1. Computation time using CUDA (GPU accelerator)

Desert locust invasion

The research in this area is in collaboration with University Gaston Berger Senegal and University of North Antsiranana Madagascar.

Desert locusts change their behavior, physiology and morphology, in response to density variations. They can exist in two different behavioral phases (Duranton,JF & Lecoq,M 1990): the first one, solitarious where individuals live in a sparse and scattered manner in recession or remission areas distributed across several Sahel countries (Uvarov 1977), and they do not venture out of their original habitat and do not affect agricultural production. The second one, gregarious where individuals are responsible for considerable damage caused to crops with potential social, ecological and environmental disasters in tropical countries (Herok, C A & Krall, S 1995).

The specificity of desert locust is that outbreaks happen only within specific conditions, leading to huge swarms, trying to survive by flying for other food sources and for escaping predators. For that they migrate from one area to another for a better living condition, they die if they fail to find a suitable breeding area. Emigration concerns winged individuals who turn to solitarious and then to gregarious before flying in a swarm.

A desert locust can live three to five months depending on weather and ecological factors. The life cycle comprises three stages: egg, larvae, and adult (Roffey, J & Popov, G 1968). Fig. 4. shows five stages, from larvae 1 to Larvae 5, compose larvae phase. In the last stage, a transformation leads to winged which become mature after some weeks. Mature females can lay eggs if humidity is sufficient.

Desert locust physical system represents the locust population in their breeding area and their interactions with weather, vegetation cover and wind, evolving from eggs to adults and flying to other cells, laying eggs.

The physical system is divided in cells, each cell contains eight arrays for eggs, larvae stages 1 to 5, winged, solitarious and gregarious individuals. Each array is subdivided in micro states representing the corresponding individuals life cycle period (Traore, M "to appear").

After some synchronous turns, the neighbors cells receive incomings adults which females can lay eggs three times in their life cycle. This model can be used in population evolution prediction, in time and space. It can also be used in individuals number counting.

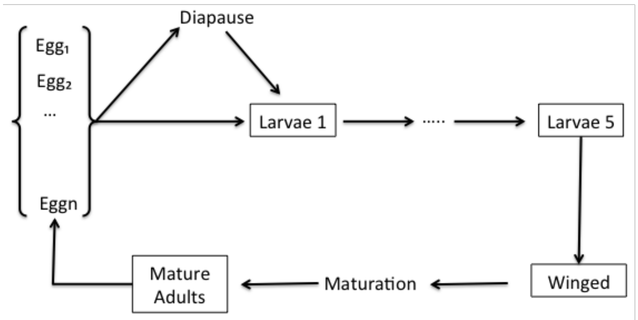

Fig.4. Desert locust life cycle

Two cases can be considered: the first one is relative to local transition between micro states in a cell, and the second one is relative to migration between cells. In this paper, the first case that represents the locust life cycle is presented.

Fig.5 shows the results of a simulation with an initial population of 50000 eggs generated randomly at the micro state, during the 15 first turns, population evolve from eggs to winged and solitarious emerge after 16 turns. A new flow of eggs appears at turn 18, cause by the laying function. Locust population develops exponentially with periodic peeks.

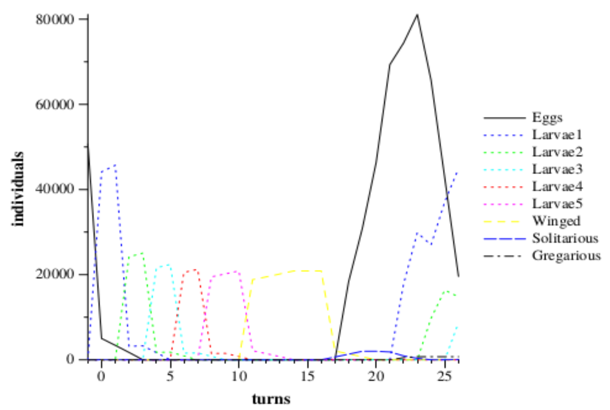

Fig. 5. Locust population evolution

WSN experimentations

Two experimentations of WSN have been done in collaboration with Indonesia and Vietnam.

A collaboration with BPPT (Agency for the Assessment and Application of Technology) and Diponegoro University Indonesia has provided results on experiments with sensors monitoring waterways and communicating via Zigbee (Xbee). The maximum distance of communication using Xbee, in this experiment is about 500 meter that is good enough to be used in an urban area.

An experiment using LoRa nodes has been done in Mekong, Vietnam. It shows good results, where LoRa can be used to communicate until 12 kilometer range.

Conclusion and discussion

Cellular modeling and simulation on environmental and physical phenomena combined with WSN observation is a promising approach to better understand environment, to reduce environmental and disaster risks and to live in harmony with environment.

Much work remains to be done, such as the integration of the WSN experimentations, ZigBee and LoRa, with NetGen/PickCell tools to model, simulate and forecast flooding in urban areas or insects in crop areas.

Such a technique has a lot of potential for modeling physical phenomena (flooding, pollutions, …) and planing cost-effective WSNs deployments in other contexts; as such we are open to cooperation with universities/research centers and state actors facing similar issues in Asia.

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