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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 are able to overcome physical constraints such as point to point radio propagation and physical sensing coverage. By building executable cell systems, we have shown that a number of conditions can be evaluated. Examples are line of sight computation and wind or water propagation in complex geographic situations. This paperexplains a method to produce automatically parallel simulators that can be federated later to address the whole problem of deployment design and physical phenomena modelling and simulations.

This work was developed in an international group (SAMES) with the purpose of building and validating tools to ease observation and control aimed at understanding environment evolution and risk reduction.

Key words: Wireless sensor networks, cellular automata, physical modeling, simulation, line of sight, insect invasion, parallel algorithms

INTRODUCTION

A 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 the environment.

A WSN regularly measures values representing the state of a physical system such as water levels for flood 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, which 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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[5]SAMES 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)
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Radio signal estimation in a city is critical due to their non-flat characteristics. We cannot predetermine where the signal goes and what places the signal can be received. It is known that a vague power estimation of the signal is not enough if the surface is not flat. So it is important to develop tools allowing the estimation of the situation and the planning of the sensor distribution in the best way possible.

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

The next section will present an overview of WSNs, followed by a short introduction on cellular modelling and simulation. An example on the line of sight computation and another example on insect invasion is introduced including the results. This paper concludes with a discussion on current and potential collaborations.

METHODOLOGY

Wireless Sensor Networks

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

Sensors measure parameters of a physical phenomenon that is being monitored. For example, water pollution in rivers and streams can be monitored by measuring some particularpollutant concentrations in the water. A combination of physical phenomena can be observed and simulated. Figure 1 shows the pollution effects of a forest fire in a river, where pollutants produced from forest fire could be observed and the phenomena could be simulated using a WSN (Hoang, VT, 2015).

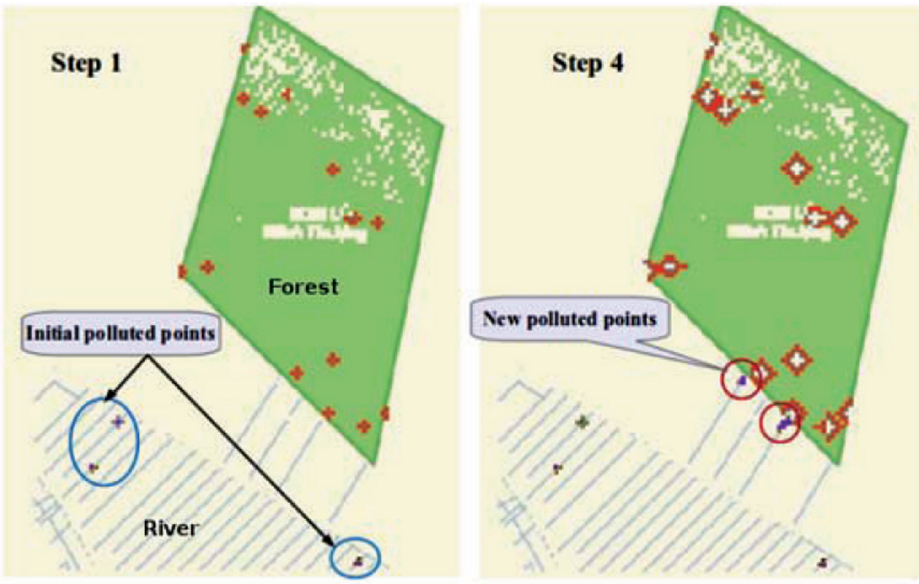

Figure 1. Two regions marked with red circles representingnew pollution created by the ashes, which were formed from the forest fire.

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

Measurement data from the sensors are sent to the server via networks. The latter could be in mesh, star, or hierarchical configurations. Well-known technologies such as GPRS and 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 analyse and forecast. For example, in the case of flood monitoring, flood forecasting is necessary to warn people in the area in order to reduce risks, protect property and save lives. External data sources might be needed to complete a model of a physical system, such as weather and topology data for a watershed model. Furthermore, data can also be used to study flood phenomenon to understand better a flood prone area. Information obtained from the analysis, modelling and simulation is then disseminated to experts, authorities and the public.

Geo-localised Cellular Modelling and Simulation

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

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

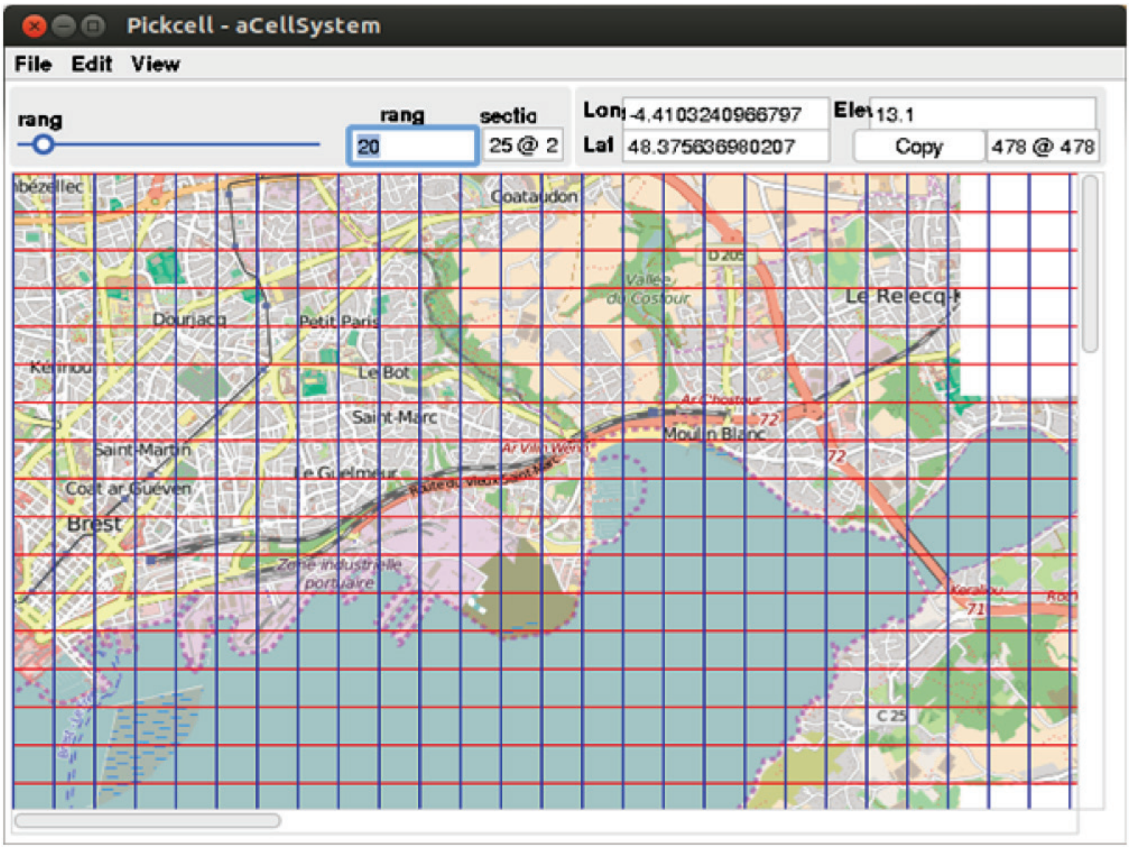

Figure 2. A screenshot of PickCell showing a map with geo-localised cells.

UBO/LABSTICC developed PickCell / NetGen, a basic tool allowing the analysis of a geographical zone, in the form of geo-localised cells in two 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. Figure 2 shows a screenshot of PickCell where latitude, longitude and elevation data are included in the system.

PickCell can generate a 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 behaviour of the cells, according to the represented phenomenon, can be added to the simulation.

Some modelling and experimentation have been carried out, for example, Brown Plant Hoppers and the light traps in Mekong Vietnam, as well as wind modelling. In this paper, two examples are presented; a line of sight computation and a desert locust invasion.

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 deployment area. The topology of the latter, 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, for example by disk modelling coverage for a particular range, by ray tracing computations, or by line of sight computations. We use this last model to summarise how the flow worked. Once Space was selected, a cell resolution was 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 neighbourhood. At this stage, additional data was fetched from servers outside: we added elevation based on each cell'sgeographic position. Simulation programs were produced in a few seconds and then they were bound to a particular behaviour, compiled and executed.

When the physical space description was obtained, we were interested to compute reachable cells in the line of sight from an emitting position. The 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 behaviour, by propagating the signal inside a tree rooted at the emitter cell, and covering the Space in concentric circles. Each new step in the algorithm covered a new circle, and the computation finished in 2× log n steps where n is the number of cells. During ray propagation, the ground profile was collected into routes that were completed progressively based on positions and elevations. Each cell could decide if the emitter was visible or not by comparing its elevation to the received profile.

The results of the line of sight computation are shown in Figure 3, where the cells with blue colours could communicate with the emitter.

Figure 3. Results of the 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 hundreds of processors, thus the computations finish at an impressive speed (see Table 1).

Table 1. Computation time using CUDA (GPU accelerator)

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	883460
3	70991	249.1000	243.6200

Desert locust invasion

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

Desert locusts change their behaviour, physiology and morphology, in response to density variations. They can exist in two different behavioural 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, CA & Krall, S 1995).

The specificity of desert locusts is that outbreaks happen only within specific conditions, leading to huge swarms, trying to survive by flying to other food sources and escapinge predators. Thus, they migrate from one area to another for better living conditions; and 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 the weather and ecological factors. The life cycle hasthree stages: egg, larvae, and adult (Roffey, J & Popov, G 1968). Figure 4 shows five stages, from larvae 1 to Larvae 5, composing of the larvae phase. In the last stage, a winged transformation occurs and the locustsbecome mature after some weeks. Mature females can lay eggs if the humidity is sufficient.

The 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 into micro states representing the corresponding individuals' life cycle period (Traore, M "to appear").

After some synchronous turns, the neighbours' cells receive incoming adults of which females can lay eggs three times in their life cycle. This model can be used in population evolution predictions, in time and space. It can also be used in individual number counting.

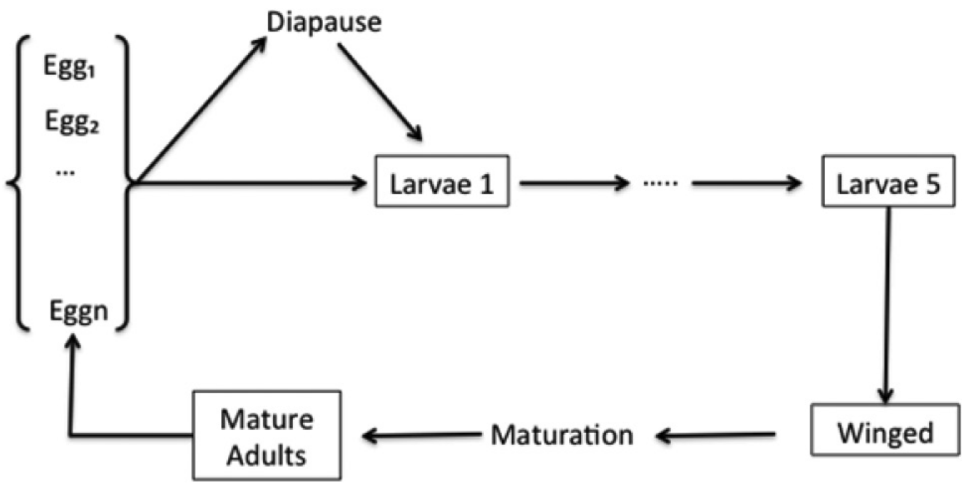

Figure 4. The lifecycle of a desert locust

Two cases can be considered: the first one is relative to local transitions 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.

Figure 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, the population evolves from eggs to winged and solitarious individualsafter 16 turns. A new flow of eggs appears at turn 18, caused by the laying function. The ocust population developed exponentially with periodic peeks.

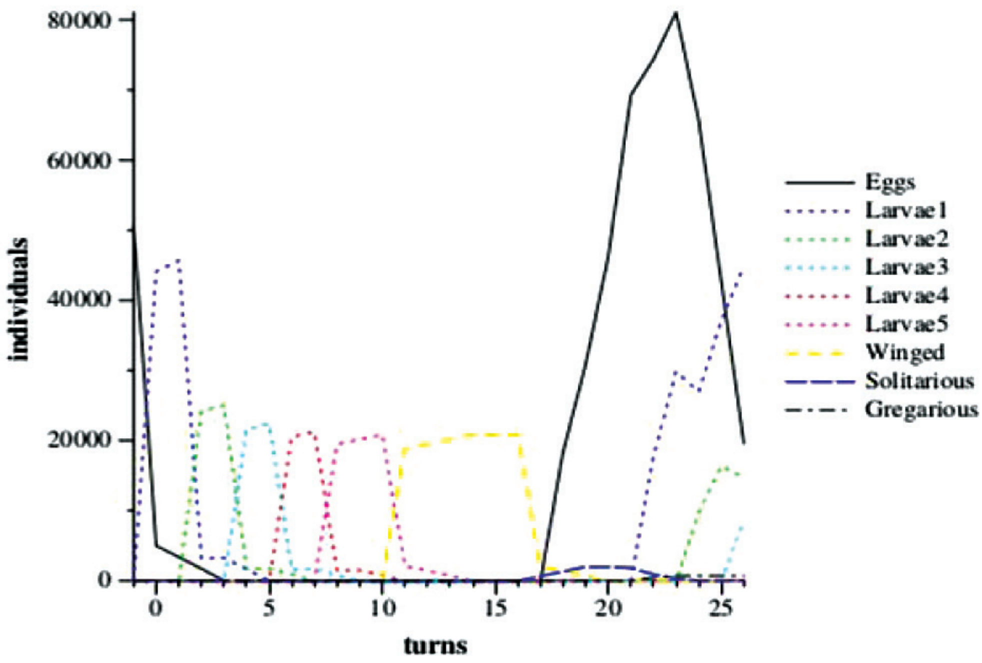

Figure 5. Locust population evolution

WSN EXPERIMENTATIONS

Two WSN experimentations 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 was about 500 metres, which was 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 could be used to communicate within a12 -kilometre range.

CONCLUSIONS AND DISCUSSION

Cellular modelling and simulation on environmental and physical phenomena combined with WSN observations are promising approaches to better understand the 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.

Suchtechniques have much potential in modelling physical phenomena (flooding, pollution,…) and planning cost-effective WSNs deployments in other contexts. As such we are open to cooperate with universities/research centres and state actors facing similar issues in Asia.

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