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iITLMA, an Intelligent Traffic Light Management Algorithm based on Wireless Sensor Networks

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Abstract
The rapid increase of vehicle population in many world cities implies the increase of road congestion and accidents. Fortunately, intelligent transport systems (ITS) with traffic signals come to solve or at lease minimize the road problems by guaranteeing for instance safe driving at road intersections. However, they can disturb and reduce the traffic fluency due to the queue delay at each traffic flow if environmental information is not taken into account. This paper aims to overcome the above concern by studying the use of distributed systems to implement intelligent transport systems through a wireless sensor network. The proposed solution is a combination of a detection unit and two communicating sensors deployed on the tracks that can react to the passage of a vehicle. This work focuses on a four-lane intersection and an algorithm allowing sensors to cooperate and manage traffic in real time according to traffic conditions is developed. The experiment area where data have been collected is Bujumbura city, the capital of Burundi. The results of data computation show that our algorithm allows a reduction of 10% in waiting time in the case of rush hours and 32% in the case of normal hours. It leads also to the maximization of the number of vehicles passing through each intersection, which allows an improvement of road safety by reducing road accidents.

Keywords Intelligent transport systems · ITS · Traffic light control · WSN

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1 Introduction

Traditionally, traffic light intersections are managed by controllers who define and implement a predetermined sequence (called a fire plan), alternating green and red lights, without taking into account traffic variations. In some urban areas, detectors count vehicles on each lane of an intersection. These devices make it possible to set up dynamic management of fire plans, using so-called adaptive methods, reacting to traffic conditions [1]. In fact, knowing the distribution of the number of vehicles per lane makes it possible to estimate the most appropriate values at a given moment of variables such as the green light time or the fire sequence making it possible to reduce, for example, the average waiting time.

The current architectures of these systems are generally organized around a fire controller that can make a local decision or communicate its information to a control center (called a traffic station) capable of retransmitting a return policy. This mode of operation is that of many operated sensor networks. The sensor network considered here consists only of fixed sensors, in order to overcome the problems related to the critical mass of users to achieve before reaching a functional application. In the case of intelligent transport systems (ITS) [2–4], the use of many low-cost sensors is an alternative to electromagnetic loops. The deployment density that can be achieved can detect and address congestion issues locally and result in distributed and more responsive ITS that do not rely on a single decision entity.

Some of those systems are reported in various works of some authors. An Intelligent Traffic Light Scheduling Algorithm Through VANETs has been proposed [5]. The algorithm aims to increase the traffic fluency by decreasing the waiting time of traveling vehicles while increasing the ratio of vehicles crossing the intersection. It is like Turky et al. [6] and Omina [7] whose algorithms use genetics taking into consideration pedestrian crossing the road and fuzzy logic respectively. The intelligence of these systems can make them autonomous. Bartłomiej Płaczek [8] proposed a self-organizing system for urban traffic control relying on prediction using agents that control traffic signals at intersections. In the same direction, Yizhe Wang et al. [9] made a Review of the Self-Adaptive Traffic Signal Control System making it capable of adjusting the signal timing parameters in real time. All the previous propositions are relying on single entity for decision. The motivation and contribution of this paper is to make many entities work in synergy and therefore increase performances. We are interested in managing traffic lights in an urban road network in order to reduce congestion and slowdowns. Some authors [10–12] tried to use WSN for traffic light management system but still had passive solution.

In this paper, after a presentation of the architecture for the sensor network deployed at an intersection, we present our algorithm, named ”Intelligent Traffic Light Management Algorithm, ITLMA in acronym to calculate the duration of the light to green taking into account traffic at the intersection, thereby reducing the average waiting time. We then show by simulation results presented in Sect. 4, that this algorithm makes it possible to reduce the waiting time of the users with respect to a predetermined fixed light plan.

2 Strategies for Deployment of Sensor Networks

The work of the literature deploying a network of sensors (magnetometers) on an intersection agrees on the fact of using at least one sensor per lane, to measure the average flow of vehicles [13]. Some variants exist, such as the ability to deploy a sensor by road, but the vision of the traffic is limited by the detection radius of the sensors [14]. Tubaishat [15] proves by simulation that using only one sensor per lane is a minimum deployment. This type of deployment may be suitable for monitoring and detecting traffic across an intersection. However, setting up two sensors instead of one alone would make it possible to more accurately measure the size of the queues. The classic adaptive intersection model, used in several works of the literature, is thus represented in Fig. 1. The traffic is monitored by two sensors located on each lane. The first is located at the traffic light. It counts the departure of vehicles from the intersection. The second is placed at an appropriate distance before the light. It counts the arrivals of vehicles [16].

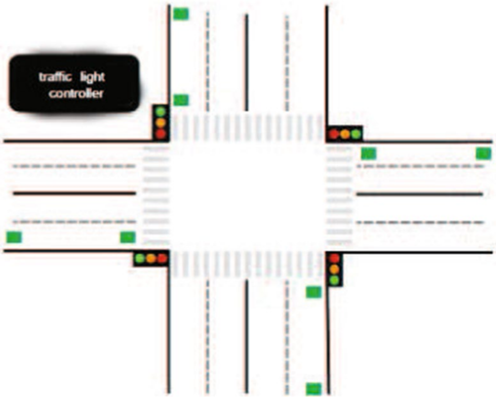
Our ITLMA algorithm distributes tasks to these different sensors on the intersection. Destination sensors monitor and count departures when the light is green. These nodes are typically located at the traffic lights, on each entrance lane or at the beginning of each exit lane (as in Fig. 1). Source sensors measure arrivals continuously. They are typically located at a fixed distance from the traffic lights on each lane.

It is important to properly adjust this distance. If it is too small, it will not cover enough vehicles. If it is too big, it will increase errors related. The distance between these two sensors, however, has an influence on the performance of the system. We agree with many authors who believe that the distance between the source and destination nodes must be a function of the time limits set on the intersection [17]. We estimate that it must correspond to the number of vehicles that can cross the intersection when the duration of the green light is at its maximum allowed, noted *tgmax*.

3 Description of the Algorithm

This problem concerns the optimization of the road traffic management in order to avoid congestion and bottlenecks in a crossroads with an autonomous and intelligent system. The objective function is the traffic light management while the instantaneous constraints concern the Lane traffic flow, the green time, the Lane, etc. The objective function is the traffic light management $F(ti, tj, tgt, Li, Lj)$ where tgt is the green time, Li is The Vehicle Line $i, 1 <= i <= 4$and ti and tj are the traffic flows. Our ITLMA algorithm depicted by Algorithm 1 allows us to calculate the time of light to green, which is adaptive to the traffic. The various sensors on the track allow us to know the number of cars, noted *nveh*, waiting on each lane. In the rest of this article, we will take into account the four-lane junction, but our ITLMA algorithm can also be adapted to the three-lane junction.

Fig. 1 Four-way intersection where all lanes are equipped with sensors



- Minimum and maximum green time According to the traffic light standard (SN 640 837), a minimum of 4 s of green time is required to cross, plus a minimum of 2 s of orange time, or 6 s in total. In the rest of our article, *tgmin* will be used to denote the minimum green time. Similarly, the maximum waiting time should not exceed 120 s (SN 640 837), which allows us to calculate the maximum green light time, noted as *tgmax*, which is 38 s. Because the waiting time of a car in a lane is equal to the sum of green times of other lanes and orange lanes. In a fixed-time controller, the sum of green and orange time is then averaged at most equal to 40 s, with a known orange time at 2 secs, so the maximum green time is 38 s.

Algorithm 1 Intelligent Traffic Light Management Algorithm

```
tgmax=38, maximum green time;
tgmin=4, minimum green time;
nmax=33, number of cars passing at maximum green time;
VARIABLES
$r$: percentage of vehicle in lane i compared to the set of vehicles in queue;
$tgt1$, $tgt2$:temporary green time respectively if $r > 25\%$ and $r \leq 25\%$;
$nvehi$: number of cars at lane $i$;
$tg$: the time allocated to green light;
$sum$: sum of all cars waiting;

//calculating the sum of the cars waiting and r
$sum = nveh1 + nveh2 + nveh3 + nveh4$;
$r = nvehi * 100/sum$;
//calculating green time
if $r > 25$ then
    Eq. 1;
    if $tgt1 < tgmin$ then
        $tg = tgmin$;
    else
        if $tgt1 > tvmax$ then
            $tg = tgmax$;
        else
            $tg = tgt1$;
        end if
    end if
else
    if $sum > 0$ then
        Eq. 2;
        if $tgt2 < tgmin$ then
            $tg = tgmin$;
        else
            if $tgt2 > tgmax$ then
                $tg = tgmax$;
            else
                $tg = tgt2$;
            end if
        end if
    else
        $tg = tgmin$;
    end if
end if
```

- Green time calculation Our algorithm allows calculating first the sum of the vehicles present in an intersection and in the entire ways, noted sum. Knowing the maximum green time, which is 38 sec, statistical data allow us to find the average number of maximum cars that can go to the green light in a maximum green time, noted *nvmax*. This average is 33 cars. By using simple calculations, we can get the green time to put the cars on hold at the traffic lights. Let's note *tgt*, this time given by the Eq. 1.

$$tgt = \frac{tgmax * nveh}{nvmax} \tag{1}$$

But this time only depends on the cars on the lane, and does not take into account the other ways, hence the appointment of the *tgt*, which is temporary green time. This formula is valid only if the number of cars present in each lane has the same portion (denoted r which is equal to *nveh*/*sum*) with respect to the totality of cars present in all the lanes, or if this portion is greater a quarter of all cars, or 25 In the opposite case, to calculate the green time, this portion must be taken into account. Hence the Eq. 1 becomes:

$$tgt = \frac{tgmax * nveh * nveh * 4}{nvmax * sum} \tag{2}$$

With 4 which represents the number of lanes in the intersection. Finally, to give the real green time to lights, our algorithm must take into account the standards on the maximum green time and the minimum green time. This means that if *tgt* is greater than the maximum green time, the *tgt* becomes *tgmax*, and if it is less than the minimum green time, it becomes *tgmin*. In the following, we use the notation $tgt1$ and $tgt2$ to designate the temporary green times calculated respectively with the formulas (1) and (2). The following page describes well our algorithm.

4 Results and Discussion

4.1 Experimental Testbed

In order to evaluate the performance of our ITLMA algorithm, an experimental testbed has been setup with two scenarios: rush hour and normal time. Assuming that sensors are set and work properly for data acquisition phase, they have been replaced by persons: two persons are placed one at the top of the traffic light and another at 50 m from the first (The sensing and acquisition process analysis using WSN is out of this study and is for the next work). Collected data are stored and computer afterward in the algorithm implemented in a C language. The real values collected on the traffic and the existing standard static light plans values have been used for comparison. The results are then exported in MS Excel to generate graphics.

4.2 Scenario 1: Rush Hour

In this first scenario, we refer to the intersection crossing the road of the Murundi people and the P.L Rwagasore road, in the city of Bujumbura, capital of Burundi, in a rush hour, the period when the traffic is more important, 7:00–8:00 am. We collected all this information on Tuesday, September 12, 2020 from 7:00 to 8:00 am. The numbers of cars on the different lanes were initialized respectively to 18, 12, 6 and 0. From these values, it was found that each 30 sec is added respectively between 5 and 10, 3 and 7,one and 5, and 0

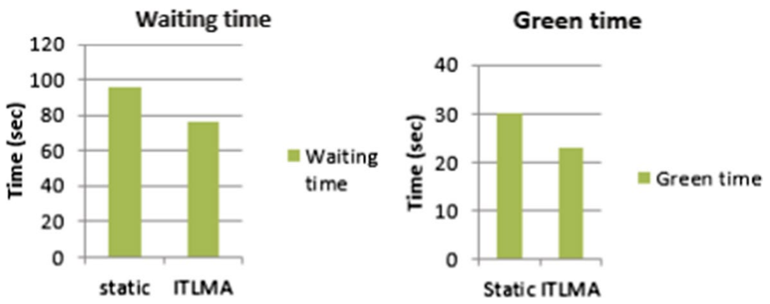


Fig. 2 Comparison of the average waiting time and average green time of our ITLMA algorithm respectively with the waiting time and average time for the static light plans (rush hour)

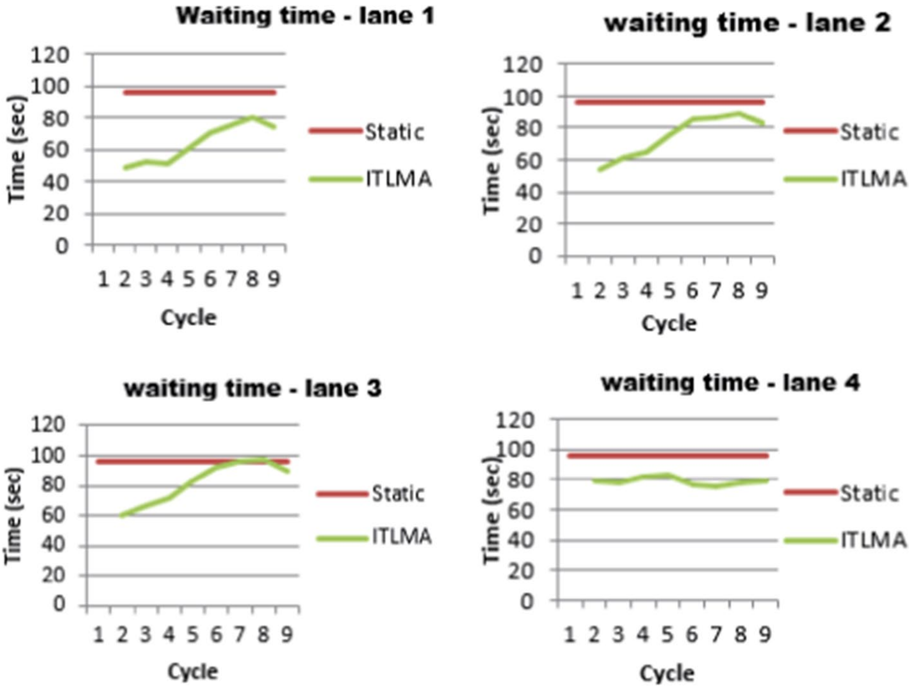


Fig. 3 Comparison of waiting time by our algorithm with waiting time for static light plans (rush hour)

and 5 cars according to our analysis on the spot. These different values allow us to evaluate our algorithm by calculating the duration of the green time on the different channels. The waiting time is calculated from the results of green time, so the sum of the green times of the other intersections. Note that for the different analyzes, we do not take into account the first cycle because we cannot know how long time cars have just waited on the different lanes during the count.

When analyzing Fig. 2, one can notice that our algorithm allows a gain (about 10%) of the waiting time compared to current static light plans during rush hours. With Fig. 3,

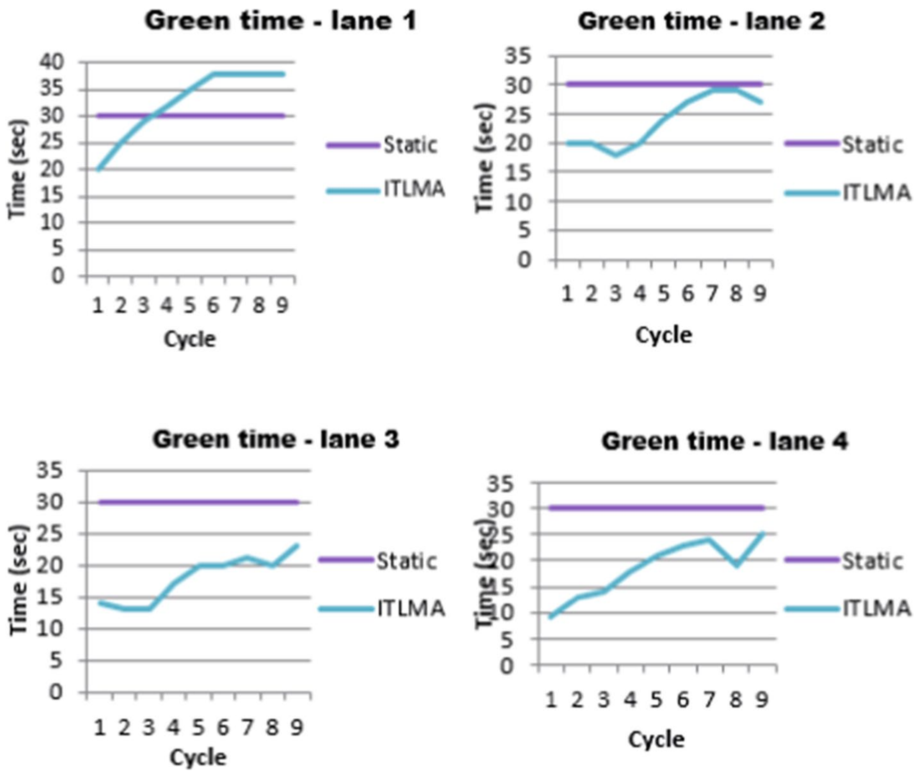


Fig. 4 Comparison of green time by our algorithm with green time for static light plans (rush hour)

we also see a gain in waiting time on each lane, and it also saves energy. Figure 4 shows a green time on lane 1 of our algorithm that is higher than that of static lights, this maximizes the number of cars passing the lane while also minimizing the waiting time as shown in Fig. 3. For the other lanes, the green time of our algorithm is lower than the static lights. All this also helps to reduce traffic jams and slowdowns at the intersection.

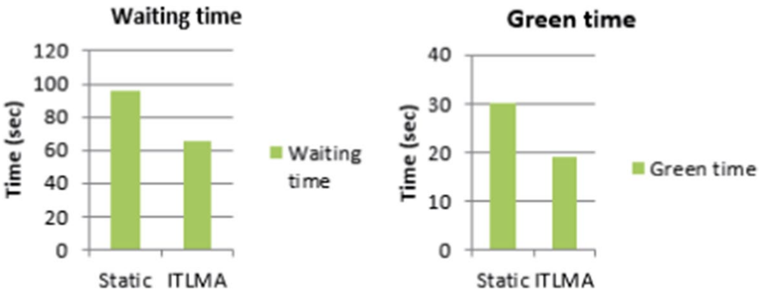


Fig. 5 Comparison of the average waiting time and average green time of our ITLMA algorithm respectively with the waiting time and average time for static light plans (normal time)

4.3 Scenario 2: Normal Time

In this second scenario, we rely on the same intersection as before, in a normal time, the period when the traffic is less important compared to Scenario 1, from 9:30 to 10:30. We collected all this information on Thursday, December 14, from 9:30 to 10:30. The numbers of cars on the different lanes were initialized respectively to 10, 5, 7 and 0. From these values, it was found that each 30 sec is added between 2 and 5 respectively, one and 4, 0 and 4 and 0 and 3 cars according to our analysis on the spot. These different values allow us to evaluate our algorithm by calculating the duration of the green time on the different lanes. The waiting time is calculated from the results of green time, so the sum of the green times of the other intersections. As in the previous scenario, we don't take into account the first cycle because we do not know the time that cars have just waited on different lanes.

Analyzing the Fig. 5, we notice is that our algorithm allows a gain (about 32%) of the waiting time compared to current static light plans during normal hours. And this gain compared to the case of the rush hour is explained very well because our algorithm calculates the green time according to the number of vehicles on the various lanes. Moreover, in the normal hours we can notice a sufficient diminution of the cars compared to the rush hour. With Fig. 6, we also see a gain in waiting time on each lane, and it also saves energy. Figure 7 shows that in all channels, the green time of our algorithm is lower than the static lights. All this also helps to reduce traffic jams and slowdowns at the intersection.

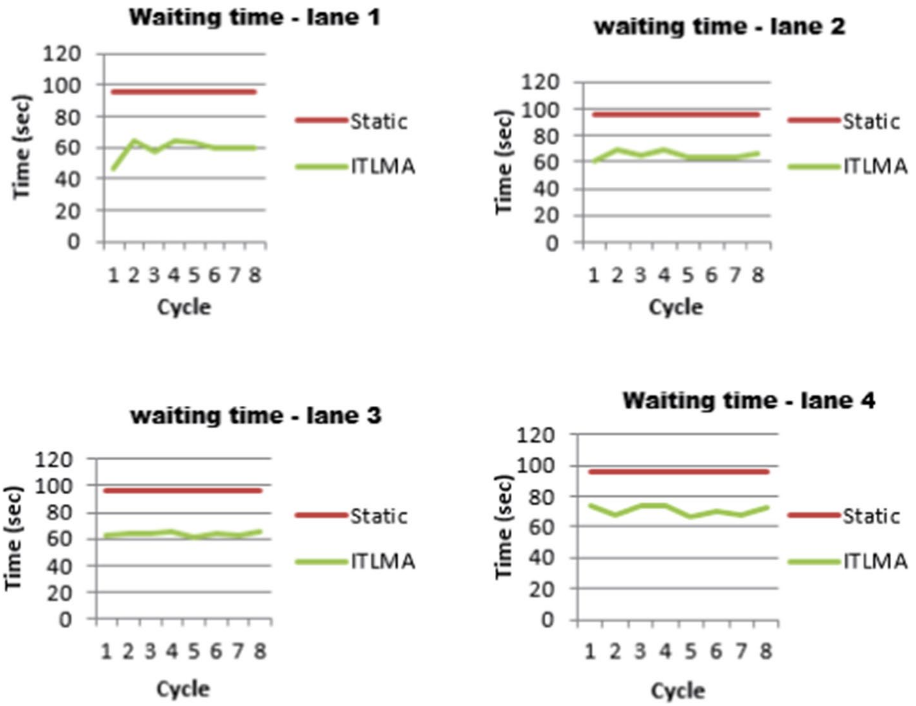


Fig. 6 Comparison of the waiting time by our algorithm with the waiting time for the predetermined light plans (case of the normal time)

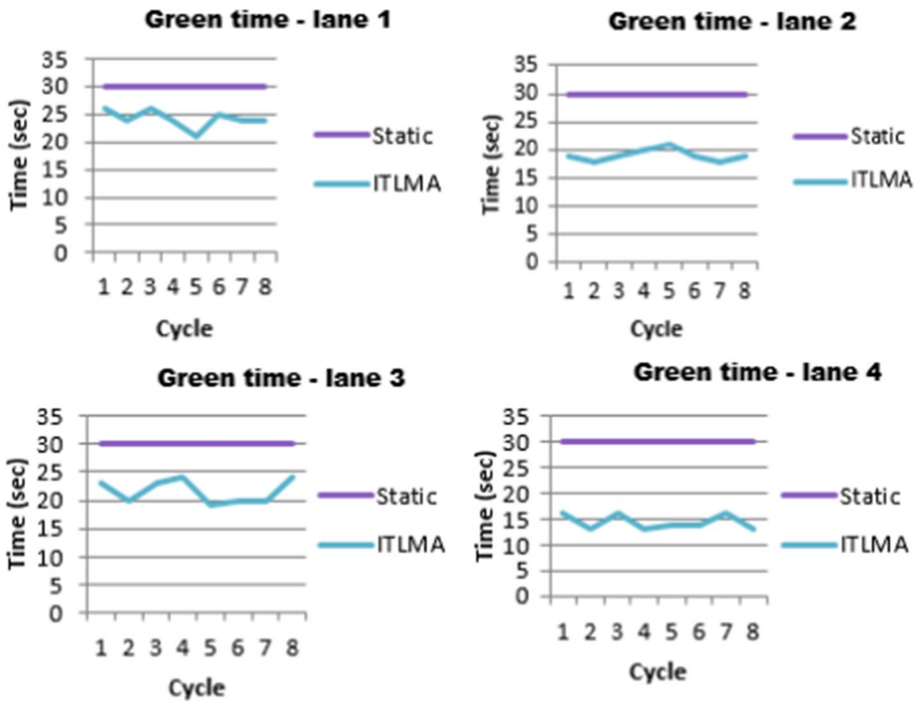


Fig. 7 Comparison of time to green by our algorithm with waiting time for predetermined light plans (normal time)

5 Conclusion

In this article, we have proposed and evaluated an ITLMA signaling control algorithm distributed over an intersection using a wireless sensor network. Based on two different scenarios, we have shown by simulation on real collected data that this algorithm is able to achieve a better wait time and green time compared to a predetermined solution. In addition to the raw performance of the algorithm, these results show that there is interest in traffic management at the intersection. For future work, a study on sensing and acquisition process using sensors will be done.

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Data Availibility All data and material used in this paper are either fully provided or referenced.

Code Availability The code is available on demand.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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- Modeling and simulation
- Engineering, applied and computational mathematics
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