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Title

論　文　題　目

Cooperative Traffic Light Control Scheme Employing V2I Network

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Cooperative Traffic Light Control Scheme Employing V2I network

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Summary

With the rapid increase of economical， the vehicle has become an indispensable part of daily life. In urban road networks, Traffic congestion has brought many environmental problems and other social problems. In this paper, a cooperative traffic light controlling algorithm for urban road networks aiming at reducing traffic congestion is proposed.

In the urban road network, the traffic pressure is unbalanced in different traffic flow direction and it can be eased by the single node traffic light optimization algorithm. However, On the other hand, the unbalanced traffic pressure also exist among different junctions in a road network. For example, we are driving on this road where the road is very congested, but not far from the other road is very smooth. This problem always happens.

Therefore, in order to reduce the waiting time of the whole road network, the dynamic connection between different traffic nodes should be taken into consideration and the traffic light scheduling algorithm should adjust according to the real-time traffic flow. For the single node condition the intelligent traffic light controlling algorithm is composed of several other algorithms. From a holistic perspective, the traffic light optimization algorithm should be a cooperative algorithm considering the conditions of different junctions.

Dedicated short range communication (DSRC) is specially design for V2V and V2I . WAVE is a layered architecture for devices complying IEEE 802.11p to operate on Dedicated Short Range Communication (DSRC) band. The DSRC in the traffic light detects the queue length of each traffic flow. Therefore, the total queue length, the total waiting time and the difference of the queue length can be calculated. Based on the traffic flow at the current traffic light cycle and the historical data, we use machine learning technique to predict the variation of the traffic flow at the next traffic light cycle.

With the purpose of reducing the road network's average waiting time and balancing the traffic pressure between different intersections, the traffic light control system adjusts the timing plan cooperatively. The genetic algorithm is utilized to obtain the optimum solution of the multi-objective functions.

With the historical and the current traffic flow data, the dynamic change of the vehicles in the road network can be predicted. In this paper, the linear regression algorithm, which is one of the machine learning methods, is used for the trend prediction. Thus we can obtain the traffic flow distribution at the next time unit. According to the next state of the road network vehicles' distribution, we are able to establish the optimal equations and set the minimum average waiting time as the optimal object. Then by using the genetic algorithm, the optimal solution as well as the adjustment amount of the traffic light timing plan can be calculated.

In addition, a novel state transition model of the road network for dynamic numerical simulation is utilized to verify the effectiveness of the proposed algorithm. According to a 4-node road network simulation result, the vehicles in the traffic flow with congestion problems will have a shorter waiting time while the vehicles in the other traffic flows will have an increased waiting time. More importantly, the average waiting time of the road network declines.

In chapter 1, the basic concept of ITS were briefly introduced. At first, in the urban road, the traffic pressure is unbalanced were described. Then, talk about the way of solving the problem.

In chapter 2, talk about the genetic algorithm. A Genetic Algorithm is a technique or a method to find the most optimum solutions for the problem through the processes of selection, reproduction, and mutations which are concepts adapted from the genetic evolution. The characteristic of the genetic algorithm to mimic the evolution theory of the nature allow it to produce multiple generations of solutions, each time eliminating unfit solutions. In genetic algorithms, the fittest solution or the optimum solution will survive throughout the processes in the end. In this paper, a genetic algorithm is used to calculate the optimum traffic light timing plan.

In chapter 3, a cooperative traffic light control Scheme was given. With the purpose of reducing the road network’s average waiting time and balancing the traffic pressure between different intersections, the traffic light control system adjusts the timing plan cooperatively.

In chapter 4, the simulation-based performance Evaluation was given. Because we cannot get full time traffic flow data for simulation, the multi nodes traffic light network model is set up to obtain the full time traffic flow data. With the purpose of simplify the simulation, we present a state transition table for the road network and use matrix operations to realize the numerical simulation.

In chapter 5, I concluded the dissertation. In conclusion, compared with the fixed time scheme, the CTLC algorithm is effective to decrease the saturation and prevent the traffic jam condition. More importantly, the average waiting time of the road network declines.

In chapter 8, I stated the future. Different cities have different traffic conditions, not all road side have installed the RSU and not all vehicles have installed the OBU, especially in the small cities. We should consider how to solve the detection for the non-DSRC vehicle. Most important, if the traffic volume is great, whether DSRC can complete the statistics and feedback on the number of vehicles. This is future work.

Abstract

In this paper, a cooperative traffic light controlling algorithm for urban road networks aiming at reducing traffic congestion is proposed. Dedicated Short Range Communications (DSRC) is applied to detect the real time traffic flow. Based on the traffic flow at the current traffic light circle and the historical data, we use machine learning technique to predict the variation of the traffic flow at the next traffic light circle. With the purpose of reducing the road network's average waiting time and balancing the traffic pressure between different intersections, the traffic light control system adjusts the timing plan cooperatively. The genetic algorithm is used to calculate the optimum traffic light timing plan. In addition, a novel state transition model of the road network for dynamic numerical simulation is utilized to verify the effectiveness of the proposed algorithm. According to a 4-node road network simulation result, the vehicles in the traffic flow with congestion problems will have a shorter waiting time while the vehicles in the other traffic flows will have an increased waiting time. More importantly, the average waiting time of the road network declines.

Keyword : DSRC，Genetic algorithm , Maching learning, CTLC

Chapter 1 Introduction

1.1 Background

With the rapid increase of economical， the vehicle has become an indispensable part of daily life. In urban road networks, Traffic congestion has brought many environmental problems and other social problems. For the purpose of easing the traffic congestion problem, the scheduling algorithm for the traffic light network is proposed [1]. By means of reducing the waiting time of the lane with the congestion problem and increasing the queuing time of the traffic flow which is correspondingly smooth, the average waiting decreases as well as the carbon emission [2][3][5].

On the one hand, the traffic pressure is unbalanced in different traffic flow direction and it can be eased by the single node traffic light optimization algorithm. However, On the other hand, the unbalanced traffic pressure also exist among different junctions in a road network [6]. As is shown in fig.1, the traffic flow from A to B suffers from the congestion while the traffic flow from B to C has few vehicles. When considering the road network as a whole, the intersection A is more crowded than the junction C. Therefore, in order to reduce the waiting time of the whole road network, the dynamic connection between different traffic nodes should be taken into consideration and the traffic light scheduling algorithm should adjust according to the real-time traffic flow.

For the single node condition the intelligent traffic light controlling algorithm is composed of several other algorithms. From a holistic perspective, the traffic light optimization algorithm should be a cooperative algorithm considering the conditions of different junctions.

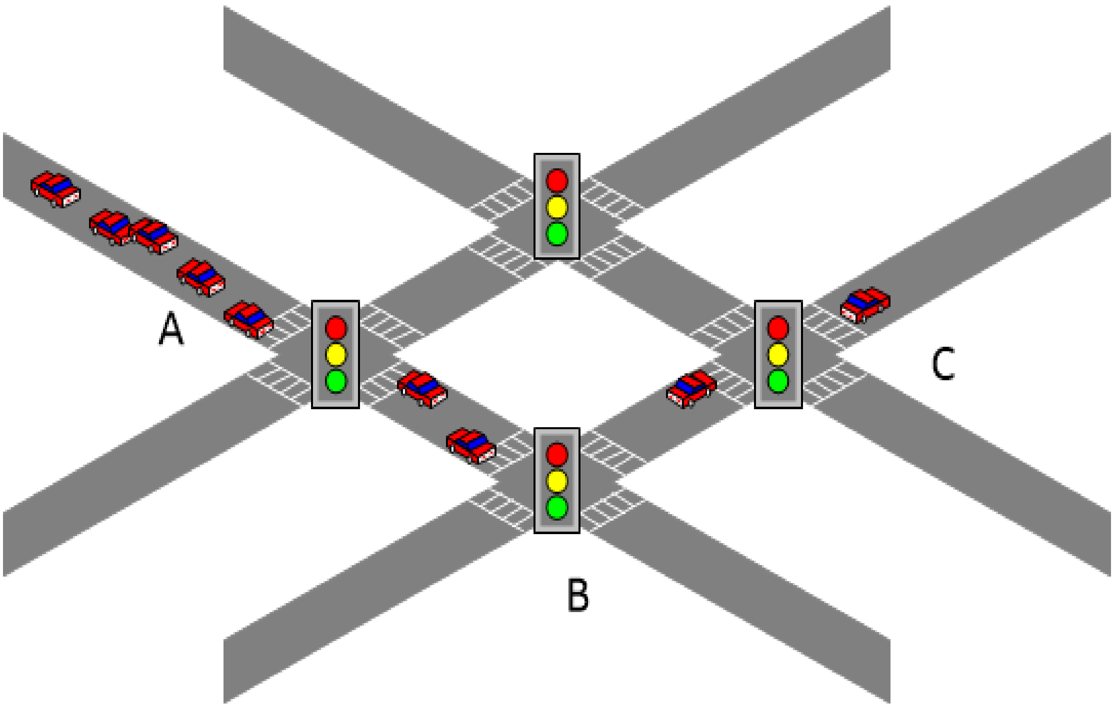

Figure 1 The sketch map of the urban road network

1.2 Introduction of ITS

ITS is a new technology which used to improve the safety, efficiency and convenience of transportation, both for goods and for people. The original idea of ITS was born in 1980s. A glance at the current state of transportation, roads equipped with electronic tolling and variable messages signs, passengers vehicles with navigation products and emergency notification systems, commercial vehicles equipped for nonstop weighting and cross-border credentials checking, transmit vehicles containing location and communications systems, infrastructure to automatically track and support the better management of traffic flow. We can confine that ITS is gaining widespread acceptance within the transportation community and by general public.

The mainstreaming of ITS is also evident in the private sector, the critical engine of technological innovation in the market. Advances in wireless communications are widening the national and global information infrastructure, giving individuals seamless access to information anywhere, any time. ITS is taking advantage of these technological developments, including the explosive growth of the internet. Automotive manufactures are coming to view wireless communications as an important complement to their relationship with their customers.

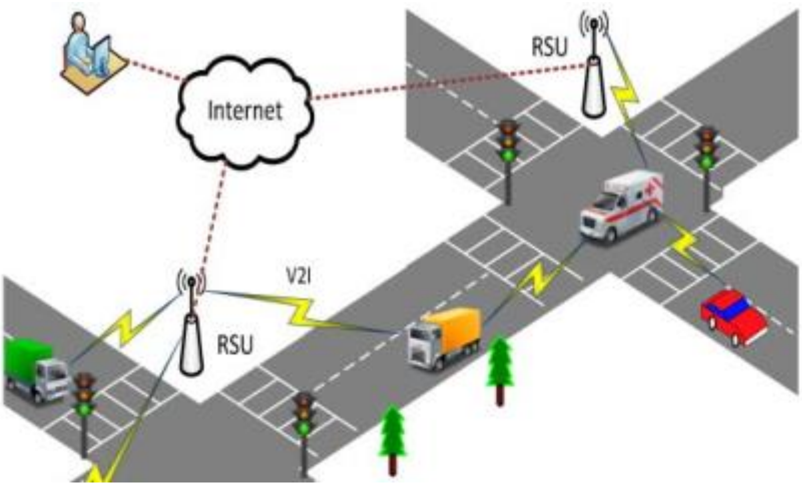

Figure 2 V2I network scenario

1.3 key Technologies for ITS

Wireless Networks.

Similar to technology commonly used for wireless internet access, wireless networks allow rapid communications between vehicles and the roadside to transmit traffic and public transit information, bur have a range of only a few hundred meters. However ,this range can be extended by each successive vehicle or roadside node passing information onto the next vehicle or node by mutli-hops.

Radio wave or infrared beacons

VICS uses radio wave beacons on expressways and infrared beacons on trunk and arterial roadway to communicate real-time traffic information. Arterial roadways are moderate capacity roadways just below highways in level of service, a key distinction is that arterial roadways tend to use traffic signals. Arterial roadways carry large volumes of traffic between areas in urban centers.

Roadside camera recognition.

Camera based or tag based schemes can be used for zone-based congestion charging systems, or for charging on specific road. Such systems use cameras placed on roadways where drivers enter and exit congestion zones. The cameras use ALPR(Automatic License Plate), based on optical character recognition(OCR) technology, to identify vehicle license plates, this information is passed digitally to back-office servers, which assess and post charges to drives for their use of roadways within the congestion zone.

Global positioning system(GPS)

GPS is the core technology behind many in-vehicle navigation and route guidance systems. The GPS receivers embedded in vehicle, acting as on-board units. These on-board units can be used for receiving signals from several different satellites and then to calculate the device's position. Therefor, this requires line of sight to satellites, which can inhibit use of GPS in downtown setting due to 'urban canyon' effects. Usually location can be determined within 10 meters. Several countries, notably Holland and Germany, are using or will use OBUs equipped with satellite-based GPS devices to record miles traveled by automobiles and trucks in order to implement user fees based on vehicle miles traveled to finance their transportation systems.

Dedicated short range communications (DSRC)

DSRC is a subset of radio frequency identification technology, widely known as a short to medium range wireless communication channel, operating in the 5.8 GHz band or 5.9GHz band wireless spectrum, specifically designed for automotive uses. DSRC enables two way wireless communications between the vehicle and roadside equipment (RSU or RSE). DSRC is a key enabling technology for many intelligent transportation systems, including vehicle to infrastructure (V2I) integration, vehicle to vehicle (V2V) communication, adaptive traffic signal timing, electronic toll collection, congestion charging, electronic road pricing, information provision.

Mobile Telephony

ITS applications van transmit information over standard third or fourth generation mobile telephone networks. Advantages of mobile network capacity may be required if vehicles are fitted with this technology, and network operators might need to co cover these costs. Mobil telephony may not be suitable for some safety critical ITS applications since it may be too slow.

Probe vehicle s or devise.

In several countries, the probe vehicles can be used to report vehicles' speed and location to a central traffic operations management center, and these probe data is aggregated to generate an area wide picture of traffic flow and to identify congested location. Extensive research has also been performed into using mobile phones that drivers often carry as a mechanism to generate real time traffic information, using the GPS derived location of the phone as it moves along with the vehicles. As a related example, in Beijing, more than 10,000 taxis and commercial vehicles have been outfitted with GPS chips that send travel speed information to a satellite, which then sends the information down to Beijing transportation information center, which then translates the data into average travel speeds on every road in the city.

1.4 ITS in various countries

There were five key classes benefits brought by applying information technology to a country's transportation network, the following listed these five benefit:

(1)To ensure the safety of driver and pedestrian

(2)To reduce traffic congestions

(3)To enhance personal mobility and convenience

(4)To being great environmental benefits

(5)Boosting productivity and expanding economic and employment growth.

Considering the great benefits of ITS , more and more countries devoted lots funds to develop the ITS.

Table 1 underlying of ITS

ITS Category	Specific ITS Applications
Advanced Traveler Information Systems (ATIS)	Real time traffic information position Route guidance Parking information Road side weather information systems
Advanced Transportation Management systems (ATMS)	Traffic operations centers Adaptive traffic signal control Dynamic message sings Ramp metering
Advance Public Transportation systems(APTS)	Real time status information for public Automatic vehicle location Electronic fare payment
V2I and V2V	Cooperative intersection collision avoidance systems Intelligent speed adaptation
ITS enabled transportation pricing systems	Electronic toll collection Congestion pricing

Japan

Japan pay a lot of money on ITS, which enable japan to play a leader role in the world. To collect and transmit traffic information, japan created the first vehicle information communications system (VICS) in 1996. Smartway finished concept development in 2004 and put into partial deployment in 2007. Using 5.8 GHz DSRC technology, Smartway can provide visual information of road conditions and use DSRC enable roadside unit to alert drives on the main lanes of the presence of merging vehicles and sends appropriate warnings. There are so many services based ITS were used in Japan.

Singapore

Singapore is a world leader in intelligent transportation systems based on ITS:

(1) Probes vehicles to collect traffic information,

(2) Electronic road pricing for congestion charging

(3) Nationwide deployment of adaptive computerized traffic signals

(4) Use of traffic management ITS applications.

Singapore's Land Transport Authority (LTA) has responsibility for all modes of transportation in the country and oversees implementation of intelligent transportation systems in Singapore. Singapore collects real-time traffic information through a fleet of 5,000 taxis which act as vehicle probes, feeding their speed and location information back to Singapore's Traffic Operations Management Center, enabling it to generate an accurate picture of traffic flow and congestion on Singapore's roadways from this critical mass of probe data.

Singapore implemented a fully automated electronic road pricing (ERP) system that uses DSRC with an in-vehicle unit installed in each car that accepts a prepaid stored-value smart card called the "Cashcard."The cost of using a particular road is automatically deducted from the Cashcard when the vehicle passes an ERP gantry. The system has since been expanded beyond Singapore's downtown Restricted Zone to its expressway and arterial roadways, and now accepts credit card payment. Singapore's ERP scheme actually uses traffic speeds as a proxy for congestion. Rates are raised or lowered to achieve traffic optimization along a speed-flow curve, 45 to 65 kmph for expressways and 20 to 30 kmph for arterial roads.

Singapore's long-term ITS plans include advanced telematics that will bring location-based services and traffic information to commuters through in-vehicle devices, and advanced congestion management systems that will include both targeted and variable user road charging schemes. Singapore is at the cutting edge of predictive traffic flow modeling based on using historic and real-time traffic data.

South Korea

South Korea's strengths in several ITS application areas make it a world leader in intelligent transportation systems. South Korea has introduced a unified fare smart card system for public transportation called T-money.

South Korea's Hi-Pass electronic toll collection system, which uses 5.8GHz DSRC technology to enable non-stop cashless toll payment, covers 260 toll plazas and over 3,200 km of highway in South Korea. Five million South Korean vehicles use Hi-Pass, which has a highway utilization rate over 30 percent. South Koreans can also use their Hi-Pass card for other purchases beyond highway tolls, including at parking lots, gas stations, and convenience stores.

A central mission of the national ITS service is to create a network of traffic system which can facilitate interactions and interconnection between South Korea's large cities. Now South Korea has basically completed the basic framework of the ITS, technology standardization, electronic road maps and other related applications in the establishment.

United States

In order to improve the safety and efficiency of the nation's road transportation system, Federal and State Departments of Transportation (DOTs) cooperated with vehicle manufactures to propose the vehicle infrastructure integration (VII) based on the evaluation of the technical, economical, and political feasibility of deploying a communications system.

DOT's ITS program focuses on intelligent vehicles, intelligent infrastructure, and the creation of an intelligent transportation system through integration with and between these two components. The ITS strategic Research plan is designed to achieve a vision of a nation, multi-modal surface transportation system which features a connected transportation environment among vehicles, the infrastructure and passengers' portable device. This connected environment will leverage technology to maximize safety, mobility and environmental performance.[7] [8] [9]

1.5 Introduction of DSRC

Dedicated short range communication (DSRC) is specially design for V2V and V2I . WAVE is a layered architecture for devices complying IEEE 802.11p to operate on Dedicated Short Range Communication (DSRC) band. The DSRC in the traffic light detects the queue length of each traffic flow. Therefore, the total queue length, the total waiting time and the difference of the queue length can be calculated. Then establish the multi-objective functions of the minimum total waiting time, the minimum total queue length, the minimum queue length difference and the minimum vehicle emission and set the traffic light timing plan as the constraint function. The genetic algorithm is utilized to obtain the optimum solution of the multi-objective functions.

1.6 Contribution of the Dissertation

With the historical and the current traffic flow data, the dynamic change of the vehicles in the road network can be predicted. In this paper, the linear regression algorithm, which is one of the machine learning methods, is used for the trend prediction. Thus we can obtain the traffic flow distribution at the next time unit.

According to the next state of the road network vehicles' distribution, we are able to establish the optimal equations and set the minimum average waiting time as the optimal object. Then by using the genetic algorithm, the optimal solution as well as the adjustment amount of the traffic light timing plan can be calculated.

According to a 4-nodes road network simulation result, the vehicles in the traffic flow with congestion problem will have a shorter waiting time while that in others traffic flow will increases the waiting time properly. The declines of waiting time means that the chances of traffic jams are greatly reduced.

Chapter 2   A Genetic Algorithm

2.1 An Overview of Genetic Algorithm

Science arises from the very human desire to understand and control the world. Over the course of history, humans have gradually built up a grand edifice of knowledge that enables us to predict, to varying extents, the weather, the motions of the planets, solar and lunar eclipses, the courses of diseases, the rise and fall of economic growth, the stages of language development in children, and a vast panorama of other natural, social, and cultural phenomena. More recently we have even come to understand some fundamental limits to our abilities to predict. We have developed increasingly complex means to control many aspects of our lives and our interactions with nature, and we have learned, often the hard way, the extent to which other aspects are uncontrollable.

The goals of creating artificial intelligence and artificial life can be traced back to the very beginnings of the computer age. The earliest computer scientists—Alan Turing, John von Neumann, Norbert Wiener, and others—were motivated in large part by visions of imbuing computer programs with intelligence, with the life–like ability to self–replicate, and with the adaptive capability to learn and to control their environments. These early pioneers of computer science were as much interested in biology and psychology as in electronics, and they looked to natural systems as guiding metaphors for how to achieve their visions. It should be no surprise, then, that from the earliest days computers were applied not only to calculating missile trajectories and deciphering military codes but also to modeling the brain, mimicking human learning, and simulating biological evolution. These biologically motivated computing activities have waxed and waned over the years, but since the early 1980s they have all undergone a resurgence in the computation research community. The first has grown into the field of neural networks, the second into machine learning, and the third into what is now called "evolutionary computation," of which genetic algorithms are the most prominent example.[10]

Genetic algorithms (GAs) were invented by John Holland in the 1960s and were developed by Holland and his students and colleagues at the University of Michigan in the 1960s and the 1970s. In contrast with evolution strategies and evolutionary programming, Holland's original goal was not to design algorithms to solve specific problems, but rather to formally study the phenomenon of adaptation as it occurs in nature and to develop ways in which the mechanisms of natural adaptation might be imported into computer systems. Holland's 1975 book Adaptation in Natural and Artificial Systems presented the genetic algorithm as an abstraction of biological evolution and gave a theoretical framework for adaptation under the GA. Holland's GA is a method for moving from one population of "chromosomes" (e.g., strings of ones and zeros, or "bits") to a new population by using a kind of "natural selection" together with the genetics−inspired operators of crossover, mutation, and inversion. Each chromosome consists of "genes" (e.g., bits), each gene being an instance of a particular "allele" (e.g., 0 or 1). The selection operator chooses those chromosomes in the population that will be allowed to reproduce, and on average the fitter chromosomes produce more offspring than the less fit ones. Crossover exchanges subparts of two chromosomes, roughly mimicking biological recombination between two single−chromosome ("haploid") organisms; mutation randomly changes the allele values of some locations in the chromosome; and inversion reverses the order of a contiguous section of the chromosome, thus rearranging the order in which genes are arrayed.[10]

2.2 GA Operators

The simplest form of genetic algorithm involves three types of operators: selection, crossover (single point), and mutation.

Selection: This operator selects chromosomes in the population for reproduction. The fitter the chromosome, the more times it is likely to be selected to reproduce.

Crossover: This operator randomly chooses a locus and exchanges the subsequences before and after that locus between two chromosomes to create two offspring. For example, the strings 10000100 and 11111111 could be crossed over after the third locus in each to produce the two offspring 10011111 and 11100100. The crossover operator roughly mimics biological recombination between two single−chromosome (haploid) organisms.

Mutation: This operator randomly flips some of the bits in a chromosome. For example, the string 00000100 might be mutated in its second position to yield 01000100. Mutation can occur at each bit position in a string with some probability, usually very small (e.g., 0.001).[10]

2.3 The flow of Genetic Algorithm

A Genetic Algorithm is a technique or a method to find the most optimum solutions for the problem through the processes of selection, reproduction, and mutations which are concepts adapted from the genetic evolution. The characteristic of the genetic algorithm to mimic the evolution theory of the nature allow it to produce multiple generations of solutions, each time eliminating unfit solutions. In genetic algorithms, the fittest solution or the optimum solution will survive throughout the processes in the end.

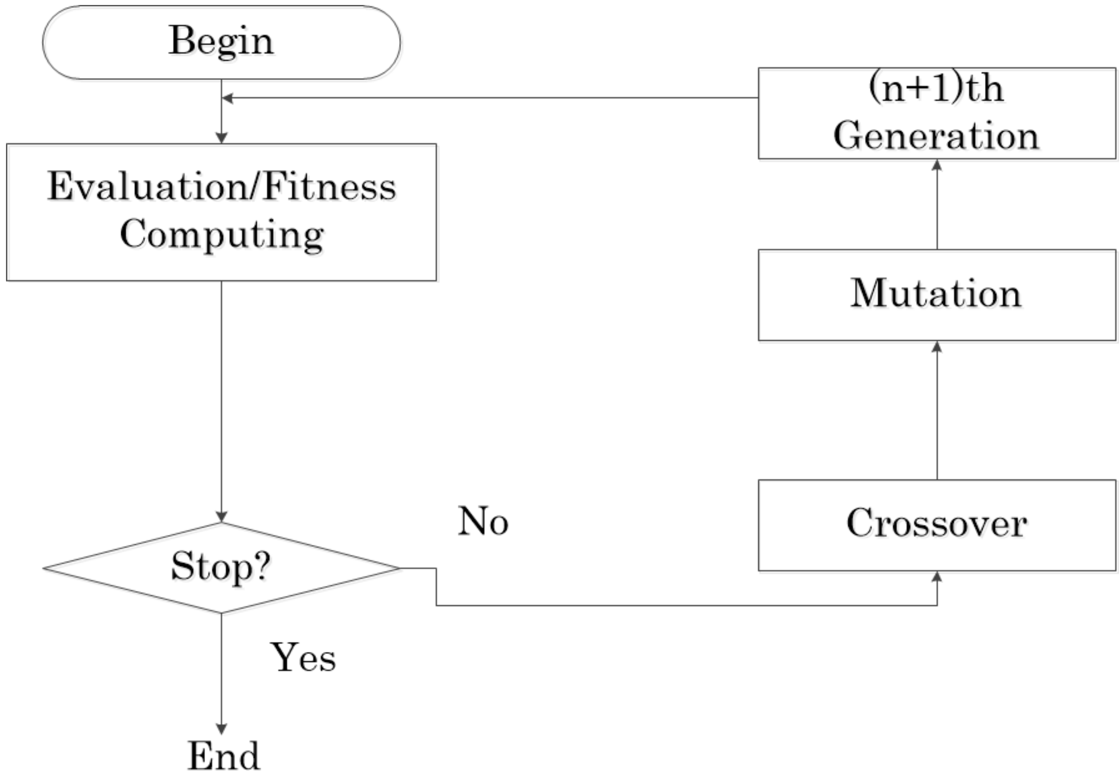

Figure 3 .The Genetic Algorithm.

2.4 Population of Chromosomes

The population is the set of the chromosomes or solutions within the boundaries that need to be determined. In the traffic flow control, the chromosomes are the green time of the traffic light system. So, the population boundaries are set to be above 0, as the green time cannot be smaller than the value 0. The number of chromosomes inside the population also needs to be decided, because the number of the solutions determines the speed of the optimization and the accuracy of the solution found. If too many solutions are generated in the population, then a greater amount of time is needed to find the fittest optimization; but, if there are too few solutions,the genetic algorithm may face the problem of finding the fittest optimizations. Therefore, a suitable number of chromosomes must be chosen, as the traffic flow control needs both speed and accuracy. In this traffic flow control, the number of the chromosomes is set to be 50 which means that the genetic algorithm will generate 50 solutions in the population and the fittest solution will be found from the 50.

The initial range of the population also needs to be selected with careful observations. With the right initial population range, Genetic algorithm is able to select the best optimum point of interest. The initial population range is the range of the chromosomes for the first generated population for the genetic algorithm to start over with; the right range will save a lot of time for the genetic algorithm to find the desired or most optimum chromosomes. If the range is too small, it will affect the diversity of the chromosomes and then cause the genetic algorithm to miss out the real optimum point in the process and lock in a local optimum. Therefore, a suitable initial range is important for the traffic flow control, which is selected as 0 to 80 in this paper.

2.5 Generations and Reproductions:

Another important field that must be considered is the number of generations that the genetic algorithm needs to run for. This is one of the stopping. Criteria for the Genetic algorithm, where the process will be stopped when the genetic algorithm has run for the predetermined number of generations. For this traffic flow control, the number of the genetic algorithms' generations is 100. This is chosen after a careful consideration in the effects of the number of generations upon the genetic algorithm. If too many generations are allowed to be run, then the genetic algorithm would suffer from a long computation time before it can stop. Another considerations, is when too few generations are run, the genetic algorithm may not be as efficient as it should be, because the genetic algorithm may not find the best chromosomes from the population.

The crossover fraction is the fraction of information from the parents or the chromosomes after the selection stage for the reproduction process. In the reproduction process, the chromosomes are selected in pairs to become the parents of the next generation of chromosomes. The crossover fraction determines what fraction of the parent should be passed to the new generation. In this traffic flow control, the cross over fraction is determined as 0.8.This means that in a pair of parents, who is A and B will produce 2 children. The children are produced by taking the fraction of values or information from their parents. In this case, one of the children will inherit

0.8 of parent A and 0.2 of parent B and the other children will inherit 0.2 of parent A and 0.8 of parent B.

Chapter 3 Overview of the System model

3.1 CTLC Algorithm Framework

In the traffic light system, the DSRC is used to capture the each traffic flow. The vehicle flow data will be used to predict the vehicle quantity of the other road junction. Assuming that the real-time queuing length of the traffic flow can be obtained by means of the DSRC, then we have a large amount of data of the vehicles quantity and the queue length of different traffic lanes. Next, use the historical data to train the autoregressive moving average model so that the short-time prediction of the traffic flow can be achieved. Therefore, the dynamic change of the vehicle distribution in the next moment will be obtained.

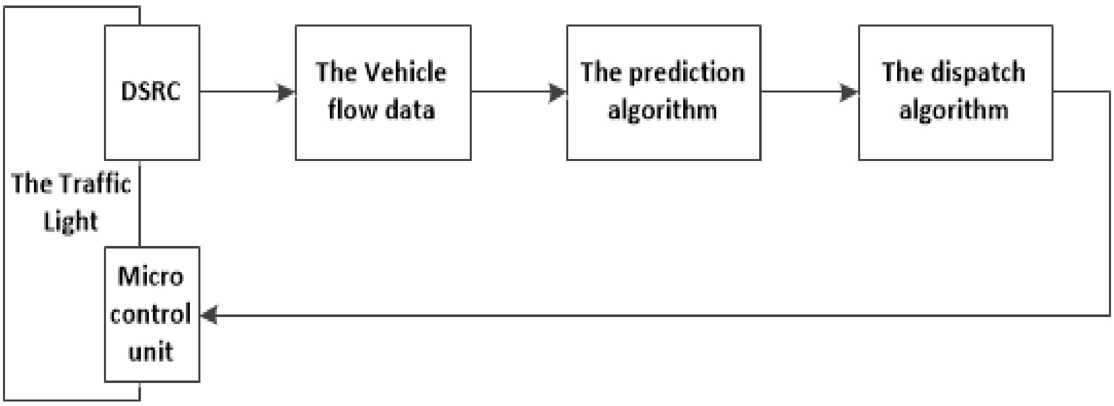

Figure 4. The CTLC Algorithm Framework.

3.2 The Queuing Length Detection

The traffic volume estimation is one of the key applications in the ITS function. It is easy to get and process the real-time traffic flow information. If we want to get the queuing length we assume that there is a RSU is set in the road. The Road Side Unit (RSU) can provide communication between vehicle and infrastructure. It is similar to a wireless LAN access point. The radio frequency identification (RFID) tag of each vehicle can be read by RSU. Since the RFID of each vehicle is unique, the RSU can get the vehicles queued length within the communication range.

According to the vehicle quantity prediction and the current queue length, the traffic light controlling plan is adjusted automatically. The green time will increase on the flow with potential congestion problem. The purpose of the algorithm is to reduce the total delay time of the multi nodes road network.

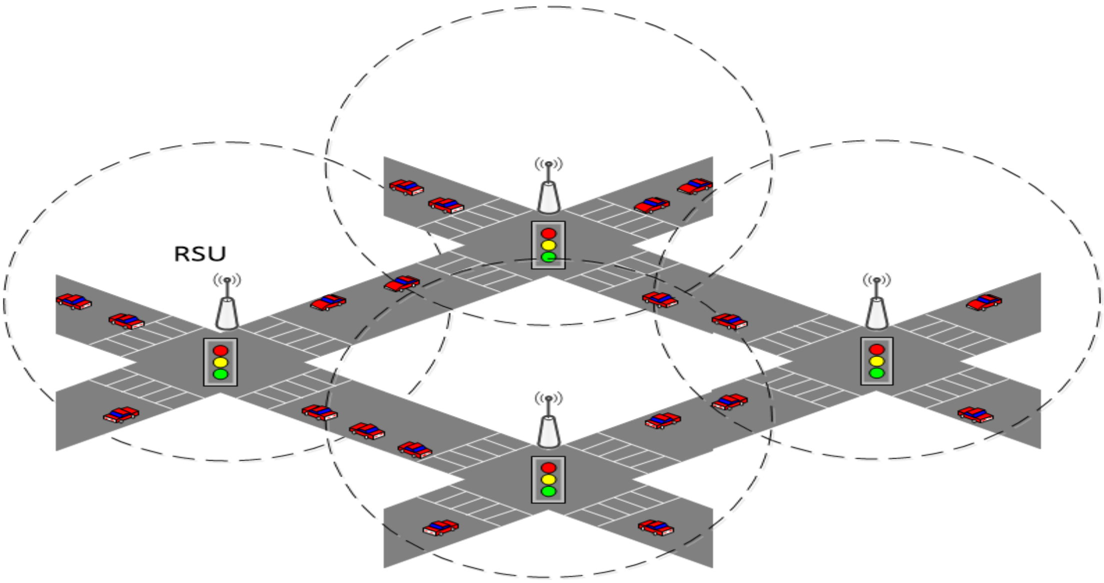

Figure 5 . The DSRC technique detects the traffic flow.

3.3 The Traffic Flow Model

Because we cannot get full time traffic flow data, the multi nodes traffic light network model is set up to obtain the full time traffic flow data. Assume that there are road junctions A and B. The flow prediction model can be described as follows.

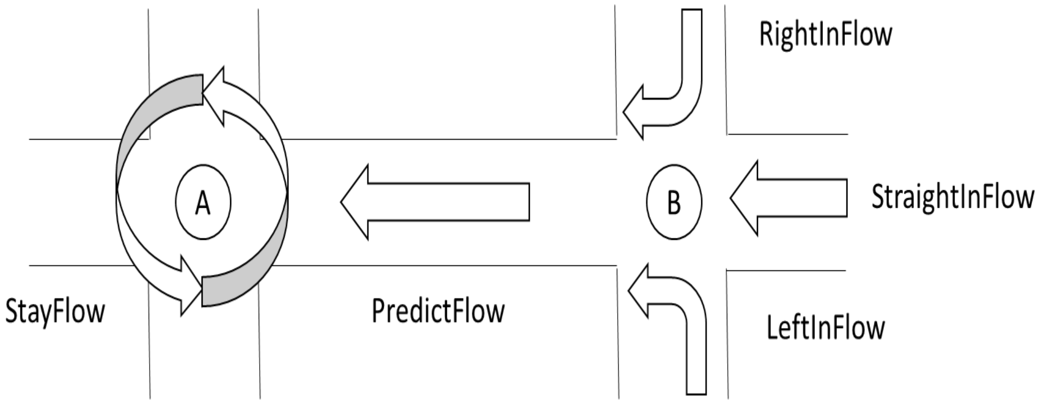

Figure 6 . The traffic flow Model.

It means that as for the current traffic light A, the vehicle from the traffic light B has three choices to arrive A. The vehicles from the north of the intersection B turn right to flow into intersection A. The vehicles from the east goes straight to flow into intersection A. In addition, the vehicles from the south turn left to flow into intersection A. By means of this rules, the connection between traffic lights A and B can be established and expressed as the following table.

$$\begin{aligned} \mathrm{Flow}(\mathrm{B} \rightarrow \mathrm{A})(t_{i+1}) &= \mathrm{StayFlow}(t_i) + \mathrm{RightInFlow}(t_i) + \mathrm{LeftInFlow}(t_i) \\ &+ \mathrm{StraightInFlow}(t_i) + \mathrm{PredictFlow}(\mathrm{B} \rightarrow \mathrm{A})(t_{i+1}) \end{aligned} \quad (1)$$

3.4 Linear Regression Algorithm

The linear regression algorithm is usually used in Machine Learning to obtain the systems prediction value. The linear regression model has the form of polynomial function.

$$(\boldsymbol{\theta_0}, \boldsymbol{\theta_1}, \cdots, \boldsymbol{\theta_n})\begin{pmatrix} x_0 \\ x_1 \\ \vdots \\ x_n \end{pmatrix} = \boldsymbol{\theta^T}\mathrm{X} = \mathbf{H}_{\boldsymbol{\theta}}(\boldsymbol{x}) = \boldsymbol{\theta_0 x_0} + \boldsymbol{\theta_1 x_1} + \cdots + \boldsymbol{\theta_n x_n} \qquad (2)$$

Where $\mathbf{x}$ is the characteristic value, $\boldsymbol{\theta}$ is the model parameters.

The cost function is used to evaluate the fitting degree of the model.

$$\boldsymbol{J}(\boldsymbol{\theta}) = \boldsymbol{min}\frac{\mathbf{1}}{\mathbf{2}\boldsymbol{m}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{m}}\left(\boldsymbol{H_\theta}\left(\boldsymbol{x}^{(\boldsymbol{i})}\right) - \boldsymbol{y}^{(\boldsymbol{i})}\right)^{\mathbf{2}} \qquad (3)$$

Where $\boldsymbol{x}^{(\boldsymbol{i})}$ is the $\boldsymbol{i^{th}}$ feature value of the training samples, $\boldsymbol{y}^{(\boldsymbol{i})}$ is the $\boldsymbol{i^{th}}$ historical data.

3.5 Vehicles Delay Model

In order to obtain the optimal traffic light control plan, the vehicles delay model is ought to be established. Suppose that it is a six phases crossing. Respectively from South to North， North to South, North to East, North to West , South to West, South to East. As shown in the Fig.7 .

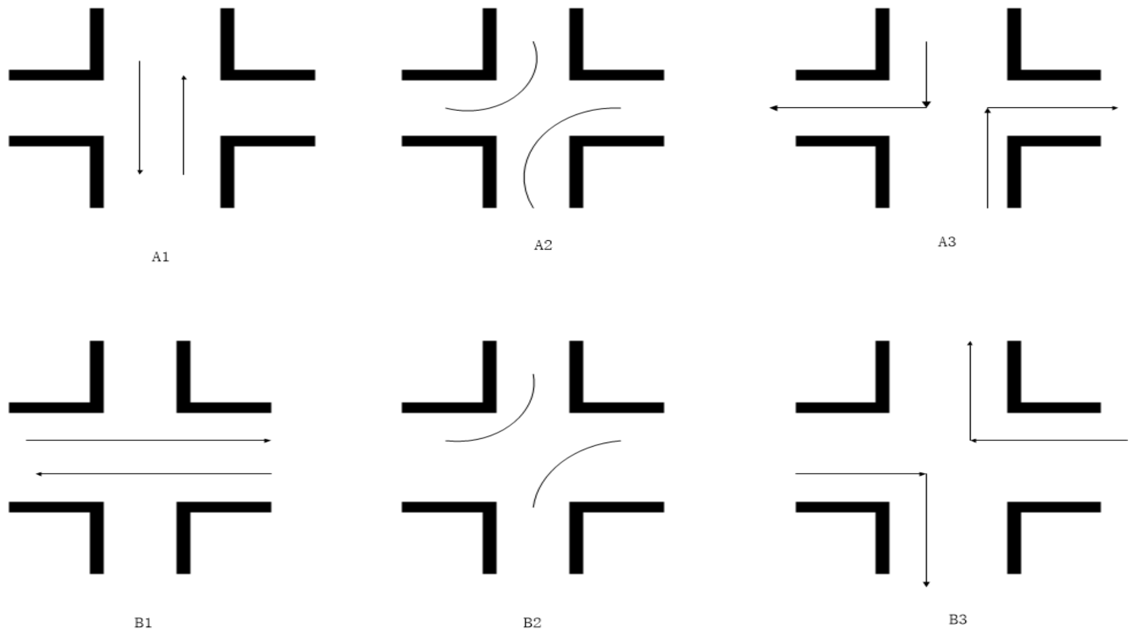

Figure 7 .The traffic phases of the intersection

In Fig.7 , A1 A2 and A3 represents the north to south direction on the green traffic light condition. Meanwhile the west to east direction is on the red traffic light condition. B1 B2 and B3 represents the adverse status.

The vehicle delay is given by the Webster delay model [2].

$$\boldsymbol{d_{ij} = \frac{c(1-\lambda_i)}{2(1-\lambda_i x_{ig})} + \frac{{x_{ij}}^2}{21_{ij}(1-x_{ij})} - 0.65\frac{c}{{q_{ij}}^2} \times {x_{ij}}^{(2+5\lambda_i)}} \qquad \textbf{(4)}$$

Where $\boldsymbol{d_{ij}}$ (s) is the average delay time from the $\boldsymbol{i^{th}}$phase to the $\boldsymbol{j^{th}}$ phase. $\mathbf{c}$ (s) is the total time of a cycle. $\boldsymbol{q_{ij}}$ (puc/h) is the arrival rate from the $\boldsymbol{i^{th}}$ phase to the $\boldsymbol{j^{th}}$ phase. $\boldsymbol{x_{ij}}$ is the saturation level. $\boldsymbol{\lambda}$ is the green split.

The average delay time on the crossing can be expressed as

$$D=\frac{\sum_i\sum_j q_{ij}d_{ij}}{\sum_i\sum_j q_{ij}}=\frac{\sum_i\sum_j q_{ij}\left[\frac{c\left(1-\lambda_i\right)^2}{2\left(1-\lambda_i x_{ij}\right)}+\frac{x_{ij}{}^2}{2q_{ij}\left(1-x_{ij}\right)}\right]}{\sum_i\sum_j q_{ij}} \tag{5}$$

The objective optimization function is the shortest of the average delay time $\mathbf{L}$,$\mathbf{L=mind}$.In the model, the shortest time of the green light of each phase should bigger than a value $\mathbf{e}$.

The constraint functions are

$$\begin{cases} \mathrm{e}\le \mathrm{t_i}\le \mathrm{c}-\mathrm{L}-\mathrm{e}\times 3 \\ \mathrm{t_i}=\mathrm{g_{ei}}\le \frac{\mathrm{cy_{imax}}}{0.8} \\ \mathrm{c_{min}}\le \mathrm{c}\le \mathrm{c_{max}} \\ \max\left|\mathrm{l_i}-\mathrm{l_j}\right|\le \mathrm{l_0} \end{cases} \tag{6}$$

Limit the saturation level of each phase to 0.8 to ensure the congestion will not happen. The minimum circle time is $\boldsymbol{c_{min}}$and the maximum circle time is $\boldsymbol{c_{max}}$ .In order to balance the traffic flow, limit the difference of queue length between different flow to a value $\boldsymbol{l_0}$.

Chapter 4 : The Simulation-based performance Evaluation

4.1 Simulation Background

Because we cannot get full time traffic flow data for simulation, the multi nodes traffic light network model is set up to obtain the full time traffic flow data. The traffic light table can be described as follow.

In this paper, a road network-oriented optimization algorithm is introduced. Firstly, the historical traffic flow data is applied to achieve the prediction by the linear regression algorithm, which can be simulated in The Matlab . Secondly, based on the current state of the traffic flow and the optimization function, the Genetic algorithm is able to calculate the optimal solution as well as the change of the traffic time plan. At last, we should analyze the average delay time of the road network. Generally, the VISSIM software is utilized to simulate the optimal traffic light timing plan for single intersection.

However, when set 2s as the analysis interval and run a 12 hours' simulation, there will be 840 times simulation.

4.2 Simulation Setup

With the purpose of simplify the simulation, we present a state transition table for the road network and use matrix operations to realize the numerical simulation. It means that as for the current traffic light 00, the vehicle from the traffic light 0 has three choices. It turns left and can arrive at the left-target traffic light 1, it can then turn right and arrive at the right-target traffic light 11 and it goes straight and can arrive the straight-target traffic light 01.

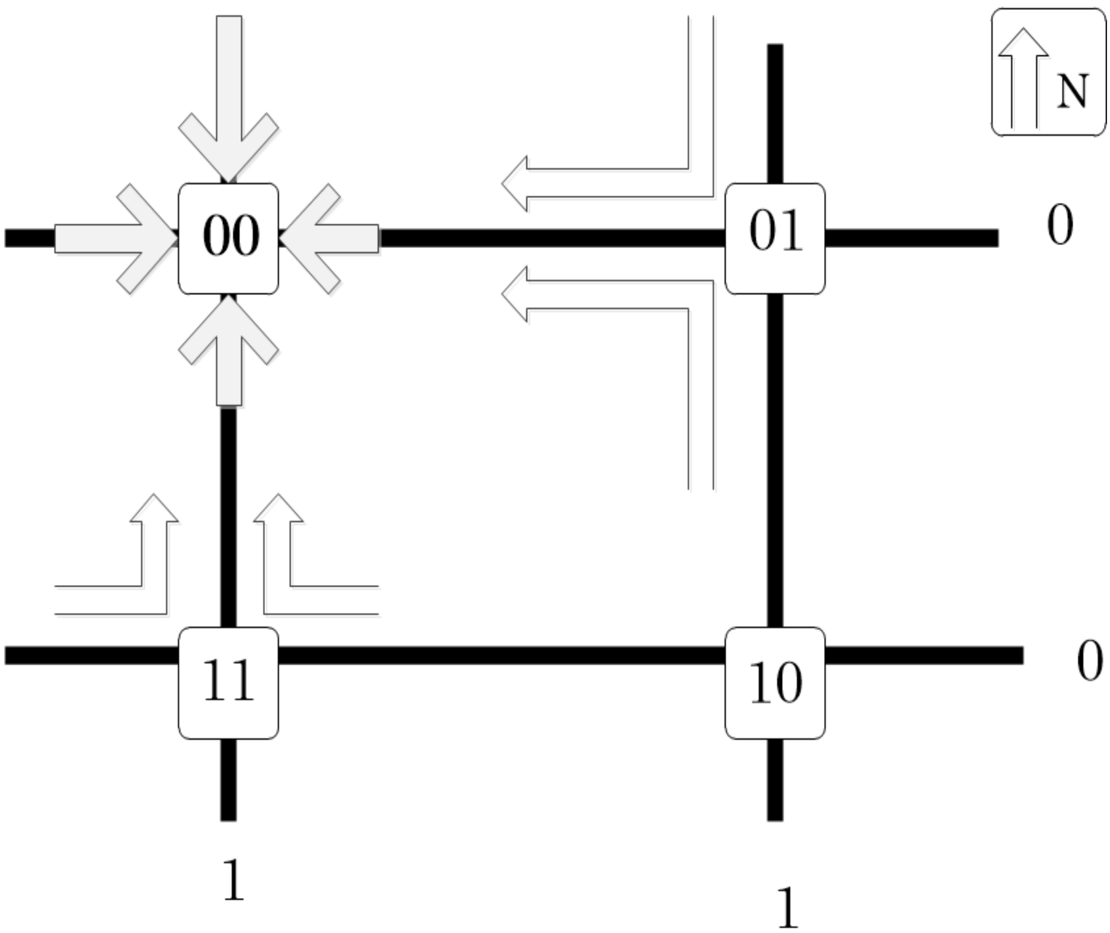

Figure 8. The code of 4-nodes road network

Intersections	Directions	Phase
00,01,10,11	West: 0001 East: 0010 North：0100 South：1000	Straight：100 Left：010 Right：001

Table 2. The traffic flow Data

The vehicles' quantity of node 00 at i period is described as [00](i), the traffic flow of node 00 is composed of 4 directions and can be described as [intersection](i) = [intersection|direction,phase] and is written as

$$[00](i) = [00|0001](i) + [00|0010](i) + [00|0100](i) + [00|1000](i) \quad (7)$$

At the next state, the input vehicles' quantity of node 00 is composed of three parts:

1. The vehicles from outside of the network as well as the south and the west.

2. The vehicles from node 01, including the vehicles from west direction of the node 01 and flow into 00 at turn right phase 001, the vehicles from east and flow into 00 at the go-straight phase 100, the vehicles from south at the turn-left phase.

3. The vehicles from south at the go-straight phase 100, the vehicles from west at the turn-left phase and the vehicles from east at turn-right phase.

As a result, the traffic flow of node 00 at the period i+1 can be written as:

$$
\begin{aligned}
[00](i+1) = [00](i) &+ \{[00|0001{,}100](i+1) + [00|0100{,}100](i+1)\} \\
&+ \{[01|0100{,}001](i+1) + [01|1000{,}010](i+1) \\
&+ [01|0010{,}100](i+1)\} \\
&+ \{[11|0001{,}010](i+1) + [11|0010{,}001](i+1) + [11|1000{,}100]\} \\
&- \{[00|1000](i+1) - [00|0100](i+1) - [00|0010](i+1) \\
&- [00|0001](i+1)\}
\end{aligned}
\tag{8}
$$

Combined with the traffic light table and the traffic flow table, the total traffic flow table can be obtain. Use (8) order linear regression model to achieve the traffic flow prediction as follow.

$$
H_\theta(t) = \theta_0 t_0 + \theta_1 t_1 + \cdots + \theta_8 t_8 \tag{9}
$$

By means of MATLAB simulation, the model parameters θ can be obtained as well as the prediction curve.

4.3 Simulation result

The simulation results of the traffic flow prediction is shown as below. The x axis is the dispatch time from 0s to 1680s and the interval is 30s. The y axis is the quantity of vehicles. The full curves is the historical data is obtained from the traffic light table and the traffic flow table. The dotted line is the predicted data of the past 7 days, the solid curve obtained from the linear regression algorithm. It can be seen that the prediction curve can predict the tendency of the traffic flow.

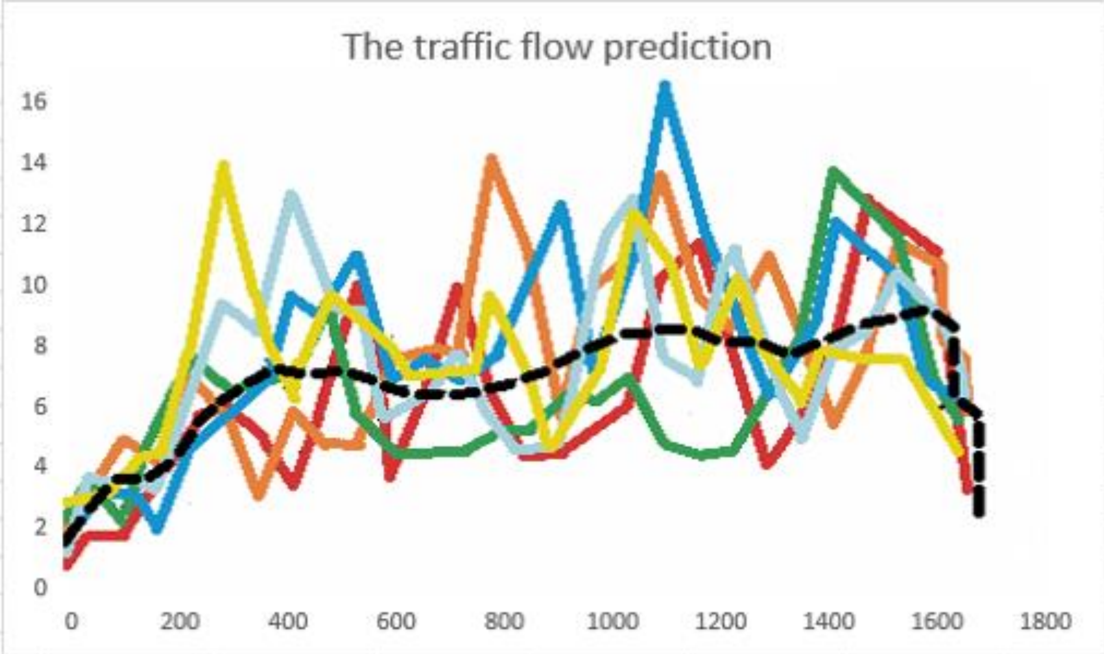

Figure 9. The simulation result of traffic prediction.

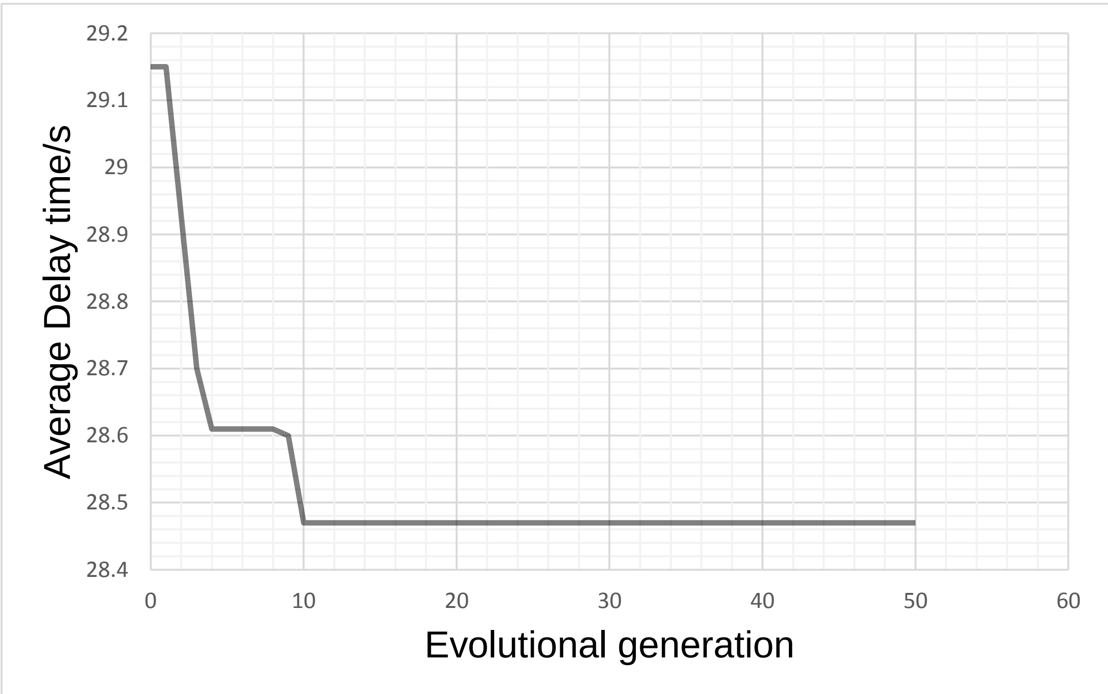

Figure 10 . The simulation result of Genetic algorithm for calculating the optimal solution

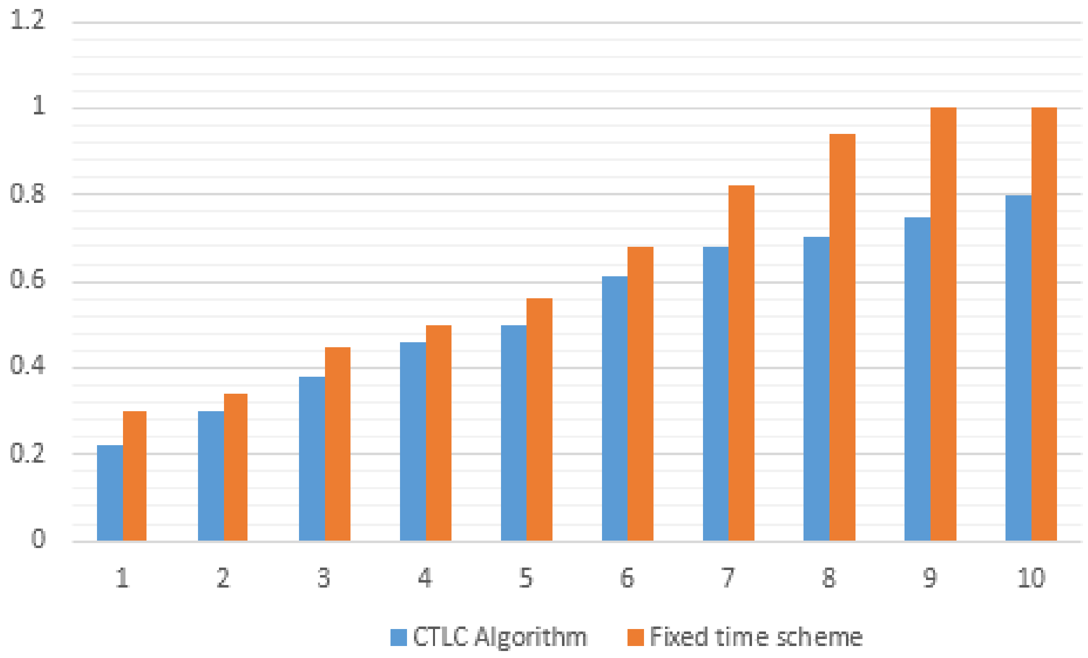

Figure 11 .The simulation result of the 4-nodes road network optimization of the average delay time

The Fig.11 demonstrates the simulation result of a 4 nodes road network algorithm application. In the figure, the Y-axis is the saturation of the traffic intersection. The X-axis is the normalized traffic density. The larger normalized traffic density value means that the more vehicles flow into the road network. In the CTLC algorithm simulation, the saturation of the traffic intersection is limited to 0.8. From the result, it can be seen that the fixed time scheme can control the intersection saturation so that when the input vehicle density is higher than 0.9, the intersection saturation is 1 and that means that traffic congestion appears. In conclusion, compared with the fixed time scheme, the CTLC algorithm is effective to decrease the saturation and prevent the traffic jam condition.

Chapter 5 Conclusion

In this paper, a cooperative traffic light controlling algorithm for urban road network aiming at reducing traffic congestion is proposed. The DSRC technology is applied to detect the real time traffic flow. Based on the traffic flow at the current traffic light circle and the historical data, we use machine learning technique to predict the variation of the traffic flow at the next traffic light circle. With the purpose of reducing the road network's average waiting time and balancing the traffic pressure between different intersections, the traffic light control system adjusts the timing plan cooperatively. The genetic algorithm is used for calculating the optimized modification amount of the traffic light timing plan. In addition, a novel state transition model of the road network for dynamic numerical simulation is utilized to verify the effectiveness of the proposed algorithm. According to a 4nodes road network simulation result, the vehicles in the traffic flow with congestion problem will have a shorter waiting time while that in others traffic flow will increases the waiting time properly. More importantly, the average waiting time of the road network declines.

Chapter 6 Appendix

θ	[00]	[01]	[10]	[11]
θ_0	-2.728e-23	4.273e-24	-2.427e-22	-1.559e22
θ_1	-3.320e-16	-3.325e-20	1.501e-18	-0.149e-19
θ_2	-3.320e-16	1.081e-16	-3.703e-15	-2.17e-15
θ_3	3.312e-13	-1.884e-13	4.625e-12	2.387e-12
θ_4	-1.329e-10	1.842e-10	-3.066e-09	-1.354e-09
θ_5	-6.360e-09	-9.388e-08	1.044e-06	3.580e-07
θ_6	1.423e-05	1.777e-05	-0.0001806	-7.035e-05
θ_7	0.0001251	0.0016805	0.0274157	0.0367806
θ_8	0.2640605	0.0226113	0.1287508	0.0389523

Table 3.The traffic flow data

Chapter 7 References

[1] Yanru Cai, Ziyang Lv, Jixin Chen, and Lurong Wu. An intelligent control for crossroads traffic light. Proceedings - 2011 8th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2011,1:494–498, 2011.

[2] Dirk Heidemann. ”queue length and delay distributions at traffic signals.”transportation research part b: Methodological. pages 377–389, 1994.

[3] Nguyen Viet Hung, Le Chung Tran, Nguyen Hoang Dung, Thang Manh Hoang, and Nguyen Tien Dzung. A traffic monitoring system for a mixed traffic flow via road estimation and analysis. 2016 IEEE Sixth International Conference on Communications and Electronics (ICCE),pages 375–378, 2016.

[4] Laura Norefia, Anna Sarrazola, Andres Acosta, Alejandro Marquez, Jorge E Espinosa, and Jairo J Espinosa. Urban traffic control in the city of medellin : A pid control approach. 2015.

[5] Chi Man Vong, Pak Kin Wong, and Weng Fai Ip. Framework of vehicle emission inspection and control through RFID and traffic lights. Proceedings 2011 International Conference on System Science and

Engineering,ICSSE 2011, (June):597–600, 2011.

[6] Zhende Xiao, Zhu Xiao, Dong Wang, and Xiaohong Li. An Intelligent Traffic Light Control Approach for Reducing Vehicles CO 2 Emissions in VANET. pages 2070–2075, 2015.

[7] Weiland, Richard J., and Lara Baughman Purser. "Intelligent transportation systems." *Transportation in the new millennium* (2000).

[8] Ezell, Stephen. "Explaining international IT application leadership: Intelligent transportation systems." (2010).

[9] Oh, Hyunseo, et al. "5.8 GHz DSRC packet communication system for ITS services." *Vehicular Technology Conference, 1999. VTC 1999-Fall. IEEE VTS 50th*. Vol. 4. IEEE, 1999.

[10] Mitchell, Melanie. *An introduction to genetic algorithms*. MIT press, 1998.

Chapter 8 Future work

As we know, Different cities have different traffic conditions, not all road side have installed the RSU and not all vehicles have installed the OBU, especially in the small cities. We should consider how to solve the detection for the non-DSRC vehicle. Most important, if the traffic volume is great, whether DSRC can complete the statistics and feedback on the number of vehicles. This is future work.

Research Achievement

1. Huan Wang, Jiang Liu, Zhenni Pan, Koshimizu Takashi, Shigeru Shimamoto .*Cooperative Traffic Light Control Approach for Reducing Traffic Congestion with V2I Network* . IEICE ,2017.

2. Huan Wang, Jiang Liu, Zhenni Pan, Koshimizu Takashi, Shigeru Shimamoto .*Cooperative Traffic Light Control Based on Machine Learning and A Genetic Algorithm*. APCC (Asia-Pacific Conference on communications),2017.