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Spatio temporal analysis of urban congestion based on potential field modification and radial basis function parallel clustering

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Abstract. Aiming at the coordinated control of city traffic area, this Paper studies the decision analysis method based on cloud computing model to form a systematic area traffic dynamic coordination and intersection signal control strategy. Considering the green time ratio of the adjacent intersection and the relationship between upstream and downstream of the traffic flow, the traffic lights timing scheme is optimized, the self-adaption coordinated control of the intersection is supported, and the informationization effect of the traffic guidance and dispersion is strengthened. In this paper, Cloud Computing Theory is introduced into the area traffic control to solve the problem in obtaining real-time traffic control information in the massive traffic detection data at present. This Paper mainly aims at the coordination control problem of area traffic signals in urban road traffic system, and through the task scheduling method, the coordinated control scheme in the traffic signal system is optimized; besides, based on cloud computing, computing mode of the configurable and shared basic resources is provided for the system so as to innovate the application of Internet of Things technology and cloud computing theory in traffic signal control, realizing that different traffic detectors and control equipment work together smoothly under the unified instruction of cloud computing platform to maximize the road traffic efficiency as much as possible.

Key words. Intelligent Transportation System (ITS), City jamming analysis, Cloud computing, Traffic control, Traffic dispatch.

1. Introduction

As a new business computing model, cloud computing, with its high scalability and high availability and other advantages, has provided a good solution to solve the problem of massive data in modern traffic management. Therefore, with the development of computer technology in recent years, cloud computing technology has

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become a research hotspot in the field of transportation. At present, the development of cloud computing has been driven by many large enterprises, represented by Google Application Software Engine (GAE, Google AppEngine), IBM “Blue Cloud” computing platform, Amazon elastic compute cloud (EC2) and so on. With the signing of the “Open Cloud Manifesto”, many IT vendors are increasingly committed to cooperating with each other to explore a unified, open new cloud computing standard to make it easier for users to understand and use the cloud environment. However, the current cloud computing has not yet formed a unified standard, and many server vendors, different vendors’ different solutions and non-interoperability between each cloud computing platform all directly affect large-scale marketization and business application of cloud computing. Especially in the transportation system, to achieve low-cost, efficient, safe and easy-to-use cloud computing platform, we are still facing many challenges, since different traffic management systems need to exchange the computing resources, and there is a need to develop a reasonable and efficient interaction protocol for the interface of cloud computing, so that different cloud computing service providers cooperate with each other in order to better play the role of strong service function of cloud computing in the traffic system. Therefore, this Paper tries to research the cloud strategy of coordinated control of city traffic region to form a new generation of area traffic coordinated control scheme supported by traffic signal control and cloud computing, promote the development & innovation of cloud computing theory and its industrial application in the traffic transportation field and help intelligent traffic and the subsequent development of the traffic era enter into a new level.

2. Task scheduling model of cloud computing platform

2.1. Cloud computing platform architecture

The overall architecture for study of cloud decision in city traffic area coordinated control mainly includes three parts: traffic information collection, cloud decision support and control scheme making. The status and function of each constituent part in the overall architecture of the system, and the logical relationship between each other are shown in Fig. 1.

(1) Traffic information collection

The underlying database relies mainly on the Internet of Things to provide the traffic information after collection and processing, such as road conditions, traffic flow, traffic flow rate, road occupancy, and time headway and other original data required by the system. Through the data mining analysis, a traffic information database of complementary attribute is formed so as to be used in developing traffic control strategy module.

(2) Cloud decision support platform

The cloud computing strategy of area traffic coordinated control is based on the two parts including the current traffic state estimation and the future traffic state prediction. Of which, the traffic state prediction is to obtain the traffic control information such as the adjacent traffic line of each traffic node, traffic of relevant roads and relevant traffic regulations after center data processing, and to generate the self-adaption coordinated control strategy of adjacent nodes through the information publishing system; the other part is current traffic state estimation, in which the traffic state of overall traffic road network within the detecting area is monitored through the statistics of traffic information; and as for emergencies, priority control scheme can be manually intervened and the past traffic data can also provide a decision basis of traffic management optimization for the Traffic Management Department.

(3) Preparation of traffic control decision scheme

Traffic control decision scheme is an important guarantee to ensure the smooth traffic and an important basis in traffic management and control, traffic guidance and other aspects. The study of area traffic coordinated control strategy is the development of single-intersection traffic control, which is expected to help decision makers improve the quality and efficiency of decision-making on the basis of single-intersection traffic control and taking into account the influence of upstream and downstream traffic states and adjacent traffic control nodes.

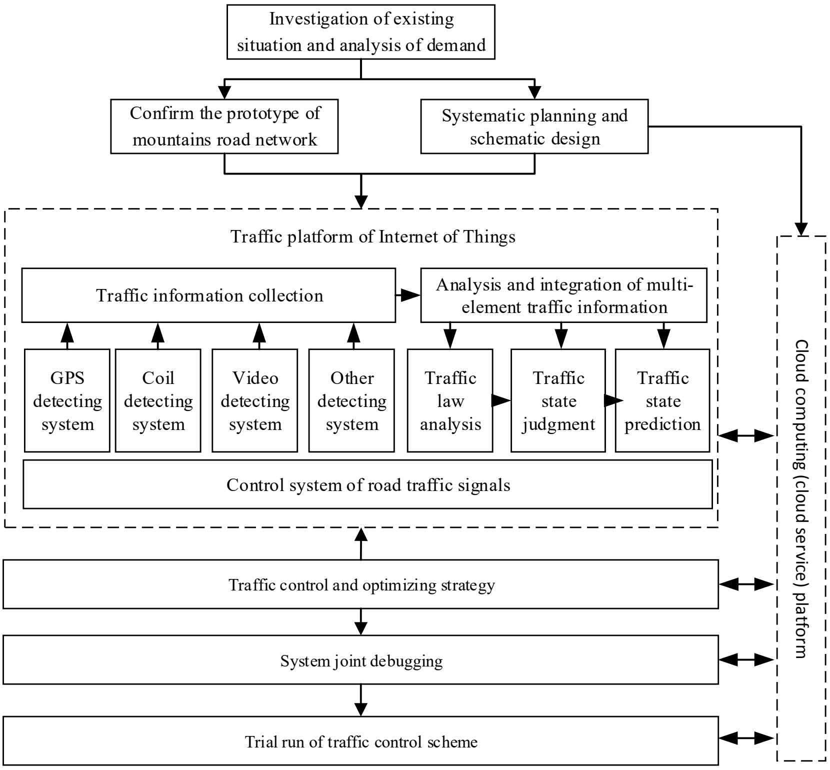

Fig. 1. Shows the overall architecture for study of clouding decision in city area traffic coordinated control

Based on the above, the study of cloud decision in city traffic area coordinated control mainly includes the application prospect and core technology of the cloud decision model in the traffic field, and discussion of the decision scheme of the road traffic coordinated control under the multiple traffic parameters. According to the application demand of the coordinated control strategy of the city traffic area, we determine the generation & publishing and optimization strategies of area traffic control and prepare the area coordinated control scheme.

2.2. Task scheduling model of node control

Since the waiting time for the vehicle arriving at an intersection signal light is uncertain, the coordinated control task's arrival at the cloud computing platform is random, that is, the time interval of control task in reaching the cloud computing platform obeys a certain random distribution, such as negative exponential distribution, poisson distribution, Erlang distribution and so on. According to the demand characteristics for computing resources of the coordinated control task, it can be divided into compute-intensive type, communication-intensive type, data-intensive type and I / O intensive type, etc. [15]. Different types of tasks generally have different data forms and problem scales to be dealt with. In order to facilitate the study, this Paper will collectively refer to a certain intersection control system in the area traffic as a control node, and assume that the control method for the same type of task be the same. Due to the autonomy and the geographical distribution characteristic of the coordinated control system, there is usually no priority constraint relationship between the control tasks submitted by different nodes, that is, the initiation of any node control is relatively independent.

Definition 1 Supposed that the traffic control task randomly arriving the cloud computing platform is expressed as a triple (T, R, W), of which

(1) $1 \leq i, j < m$; (1) $T = \{t_i | 1 \leq i \leq m\}$ represents the set of various control task types, t_i represents the Type i control task, and $t_i \cap t_i = \emptyset$, of which $1 \leq i, j \leq m$;

(2) $R = \{r_i | 1 \leq i \leq\}$ represents the set of average arrival rate of node control tasks, r_i represents the average arrival quantity of Type ti task in unit time; if $i \neq j$, then $r_i \neq r_j$ and $1 \leq i, j \leq m$;

(3) $W = \{w_i | 1 \leq i \leq m\}$ represents the set of task calculation quantity that cloud computing platform faces, wi represents the calculation quantity of Type ti control task. Therefore, the calculation task of Type $i$can be expressed as (t_i, r_i, w_i), in which $t_i \in T$, $r_i \in R$, $w_i \in W$.

As for the average arrival rate of control task to the cloud computing platform, the massive monitoring data of the platform can be used to analyze the random distribution of intervals of task arriving at the cloud computing platform by reference to the statistical method, including χ^2 test method so as to determine the theoretical distribution that the task arrival interval obeys, and estimate its parameter values.

Definition 2 The cloud computing platform in the control node task scheduling is expressed as a sextet $(C, P^{busy}_{m\times n}, P^{idle}, P^{peak}, U_{m\times n}, S)$, of which,

(1) $C = \{c_i | 1 \leq i \leq\}$ represents the set of control nodes in the cloud computing platform, where ci represents the ith control node and n is the number of control nodes;

(2) $P^{busy}_{m\times n} = \{P^{busy}_{ij} | 1 < i < m, 1 < j < n\}$ represents the matrix of execution

power of control nodes, P_{ij}^{busy} represents the execution power of Type ti task on the control node cj; if $i \neq h, j \neq k$, then $P_{ij}^{busy} \neq h_{hk}^{busy}$;

(3) $P^{idle} = \{p_i^{idle} | 1 < i < n\}$ represents the set of idle power of control nodes, P^{idle} represents the power of control node ci in idle state; if $i \neq j$, then $P_i^{idle} \neq P_j^{idle}$;

(4)

$P^{peak} = \{p_i^{peak} | 1 < i < n\}$ represents the set of peak power of control nodes, p_i^{idle} represents the power of control node ci in peak state; if $i \neq j$, then $P_i^{idle} \neq P_j^{idle}$;

(5) $U_{m\times n} = \{u_{ij} | 1 \leq i \leq m, 1 \leq j \leq n\}$ represents the matrix of average service rate of control nodes, u_{ij} represents the average service rate of control node ci to Type ti task; if $i \neq h$, then $p_{ij} \neq p_{hk}$;

(6) $S = \{s_{idle}, s_{busy}\}$ represents the set of control node states, s_{idle} represents that control node is in run but in idle state, and s_{busy} represents that control mode is in execution state.

As with the acquisition method of the control task's average arrival ratio at the cloud platform, through the analysis of the random distribution of massive monitoring data on the cloud computing platform, the service rate matrix **Um×nPIdel** of different control nodes in dealing with different types of tasks can be got, of which Ppeak and $P_{m\times n}^{busy}$ can be obtained by measurement.

2.3. Cloud computing strategy of multi-node coordinated control

The demand for traffic control at different intersections is different; some need to be provided with vertical crossing way bypass service, some pursues for the time sharing traffic service of grade crossing. In order to ensure the service quality (QoS) of the cloud platform, the traffic control signal must provide the appropriate intersection control strategy according to the actual traffic demand. At the same time, it shall develop the overall traffic efficiency of control nodes within the cloud computing platform to achieve load balancing. In this Paper, a multi-control node coordination method based on QoS is proposed, which can select the appropriate node control strategy according to the priority to coordinate the traffic demand of different intersections. And the following parameters are mainly considered:

(1) Computing time: namely the time that it takes to execute task and complete it after the task arrives at the cloud computing platform. The time required for system services can not be determined in advance and can only be estimated based on system overhead, estimated run time and the run time for other ready tasks of the task. The expected completion time Tc of Task Wi is:

$$T_c = Q_w = T_e + \sum_{k=1}^{QL_d} T_{ke}\,, \tag{1}$$

$$T_e = \frac{T_{ini} + \sum_{n=1}^{n} T_n}{N+1}, N \neq 0\,, \tag{2}$$

Where QLd represents the length of the task queue on node d, and *Te* represents the estimated run time of task *Wi*. The estimated run time of Task *Wi* is *Tini*, which is the average of the previous run time for the task. N represents the number of task executions, and *Tn* represents the *nth* run time of *Wi*. The more times Wi is done, the closer the value of *Te* is to the true completion time of the task. The smaller the value of *Te*, the faster the task will be completed. We find the node with minimum *Te* and the running on that node can ensure the real-time performance of the task.

(2) Running cost of cloud computing platform: as the cloud computing provides coordinated control service for all control nodes, the control node needs to conduct task request based on the specific control requirements of traffic flow, and the lump sum cost Cost *Wi* in executing Task *Wi* is:

$$\begin{aligned} CostW_i = & P_{cpu}C_{cpu/GHz} + P_{men}C_{men/MB} \\ & + P_{stor}C_{stor/MB} + P_{net}C_{net/Mbs} \end{aligned} \tag{3}$$

The service cost used in performing the control task is mainly generated by the consumption of equipment such as network communication, calculation and storage, etc., where P is the price of equipment's unit resource and C is the quantity of resources. In a specific cloud computing environment, costs may be slightly different, which can be ignored for the time being in order to facilitate the solution.

(3) System running overhead: includes the schedule overhead and communication overhead of cloud computing platform on task. Schedule overhead refers to the overhead generated from real-time segmentation of task and scheduling executive resources according to the demand. Communication overhead refers to the sum of data communication overhead between resource schedule or node and other nodes. The total overhead of Task *Wi* during the scheduling process is:

$$O_i = O_w + O_d \,, \tag{4}$$

$$O_w = \frac{D_i}{C_d} Dc_{ij}, \tag{5}$$

$$O_d = \sum_{\substack{v=0, \\ v \neq d}}^{n} \sum_{p=0}^{SN} \frac{D_{ip}}{C_v} DS_{dv} \,. \tag{6}$$

Where, O_i is the total overhead of cloud computing platform, O_w is task scheduling overhead, *Od* is transmission overhead. *Di* represents the total quantity of transmission data of Task W_i and C_d is the communication capability of data transmission of control node *d*. *Dcij* represents the physical distance between the two control nodes *ci* and *ci*. SN represents the number of tasks. If Task *Wi* is scheduled to Resource *h*other than other resources, its total overhead will be the minimum and the correlation degree between Task *Wi* and Resource *h*will be the highest. Therefore, scheduling the task to the resource can reduce the overhead.

$$TLV = \{TLV_{cpu}, TLV_{men}, TLV_{stor}, TLV_{net}\} \,. \tag{7}$$

Platform load balancing: If the load of the control task in the cloud computing platform exceeds the maximum load limit that the platform can tolerate, its overall performance will be reduced and the quality of the cloud service will not be guaranteed. Therefore, task should be scheduled as much as possible to the nodes with non-heavy loads to achieve load balancing. Besides, each control node should be set with a critical value of rejecting task; when control node device load exceeds the critical value, task allocation will then be rejected. The calculation formula for critical value of node is shown in (7):

3. Simulation experiment and analysis

3.1. Experimental environment and parameter setting

In order to verify the effectiveness of the cloud strategy in coordinated control of city traffic area, the Paper uses the Matlab discrete event as the simulation tool to conduct simulation experiment. The relevant parameters, value or value range involved in the experimental environment is shown in the Table 1.

When λ_i and u_{ij} values are generated randomly, the condition of $0 < \rho = \frac{\lambda}{u} < 1$ shall be met, of which:

$$\lambda = \lambda_3 + \lambda_2 + \cdots + \lambda_n ,$$

$u = \sum_{j=}^{N} (\frac{1}{n} \sum_{i=1}^{n} u_{ij})$, the condition guarantees the stationary running state of simulation platform.

Table 1. Parameters of simulation environment

Parameter	Setting	Explanation
m	8000	Total number of tasks arriving immediately
ti	$1 \leq i \leq 4$	Number of task types
n	15	Number of control nodes in the platform
λ_i	[10,15]	Average arrival rate of Type i task
u_{ij}	[1,5]	Average service rate of control node cj *to Type* ti task
wi	[1,10]	Calculation amount of Type ti task
$(\alpha, \beta, \chi, \gamma)$	(1.1,5.2,1.5,1.3) (1.1,1.4,0.3,1.5) (1.2,1.1,1.3,0.2)	Value of parameters in scheduling probability calculation formula: (1) When $C_{light} = \emptyset$; (2) When $C_{light} = \emptyset$ and $C_{normal} \neq \emptyset$; (3) When $C_{light} = \emptyset$, $C_{normal} = \emptyset$ and $C_{heavy \neq \emptyset}$.
w_{light}	0.25	Light load threshold of control node
w_{heavry}	0.75	Heavy load threshold of control node
p_i^{idle}	[50,60]	Idleness rate of control node cj
p_i^{busy}	[100,150]	Execution power of control node cj on Type ti task

3.2. Experiment and result analysis

When the node's control task enters the cloud computing platform, the platform will record the type of task and the time of its entering the platform. In the task queue of entering the cloud computing platform, the waiting time of any task can be got by minusing the completion moment of the previous task in the task queue and the arrival moment of the task. The completion time of the task is equal to the sum of its entry moment and arrival time and service time. Finally, the completion time of the task minus the time of entry into the platform is the sojourn time of the meta-computing platform to the control task. The average sojourn time of all the tasks in the cloud computing platform is the average sojourn time Timeavg of the task on that platform. According to the types of tasks ever executed by control node cj and the number of corresponding tasks, corresponding execution power and service time, the execution time of the task of control node cj in the platform $Time_j^{busy}$ and execution energy consumption $Energy_j^{busy}$ can be calculated. According to the above analysis, it can be seen that the completion time $Time_j^{total}$ on control node cj is equal to the completion moment of the last control task minus the entry moment of the first task into the platform; then the idle time of the control node cj can be expressed as:

$$Time_j^{idle} = Time_j^{total} - Time_j^{busy}\,, \tag{8}$$

The idle energy consumption of control node cj can be expressed as:

$$Energy_j^{idle} = Energy_j^{total} - Energy_j^{busy}\,. \tag{9}$$

Therefore, the total energy consumption of control node cj can be expressed as:

$$Energy_j^{total} = Energy_j^{idle} - Energy_j^{busy}\,, \tag{10}$$

The average power of control node cj:

$$Power_j = \frac{Energy_j^{total}}{Time_j^{total}}\,. \tag{11}$$

For the whole system, the completion time of all tasks is:

$$\max\{Time_j^{total} | 1 \le j \le n\}\,, \tag{12}$$

The average power of the system is:

$$Power_{avg} = \frac{1}{n}\sum_{j=1}^{n} Power_j, \tag{13}$$

Therefore, the average energy consumption in executing the control task of single node in the cloud computing platform is:

$$Energy_{avg} = Power_{avg} \times Time_{avg}\,. \tag{14}$$

In order to further explain the effectiveness of the cloud strategy in coordinated control of traffic area, this Paper analyzes the average sojourn time and the average energy consumption in execution of the task by the cloud computing platform respectively. The simulation results are shown in Fig. 2 and Fig. 3. Through the analysis of experimental result, it is found that the average energy consumption of the cloud computing platform in executing tasks is linearly decreased with the increase of the number of control nodes. When the number of control nodes is 6 or 7, the average energy consumption of the platform in executing tasks is the minimum; under the condition of equal energy consumption, the system has better scalability when the number of control nodes is 6 or 7. As the number of control nodes continues to increase, the average energy consumption of the platform in executing tasks begins to increase and exponentially increases, whose reason analysis can be summarized as follows:

(1) When the number of control nodes increases from 1 to 6, the average sojourn time of the control task in the cloud computing platform decreases exponentially (as shown in Figure 2), but the average energy consumption of the cloud computing platform basically tends to be stable (as shown in Fig 3), which results in the gradual decreased average energy consumption of platform in executing tasks in the process; in addition, due that the absolute value of average power of cloud computing platform at the moment is relatively small, the decreasing trend is linear.

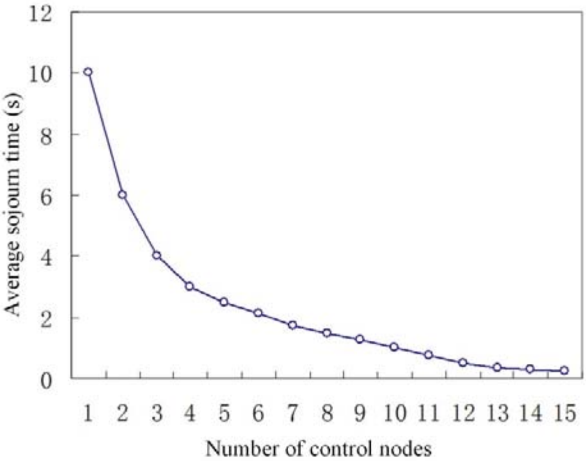

Fig. 2. Average sojourn time of cloud platform

(2) When the number of control nodes increases from 7 to 15, the decreasing trend of the average sojourn time of task becomes flat (as shown in Fig. 2), but the average power of the cloud computing platform increases exponentially (as shown in Figure 3), resulting in the gradually increased average energy consumption of the task in the process; in addition, due that the absolute value of average power of the system at the moment is relatively big, the growth trend is exponential.

It can be seen that, under the condition of equal energy consumption, the system has the best scalability when the number of control nodes is 6 or 7. For the actual

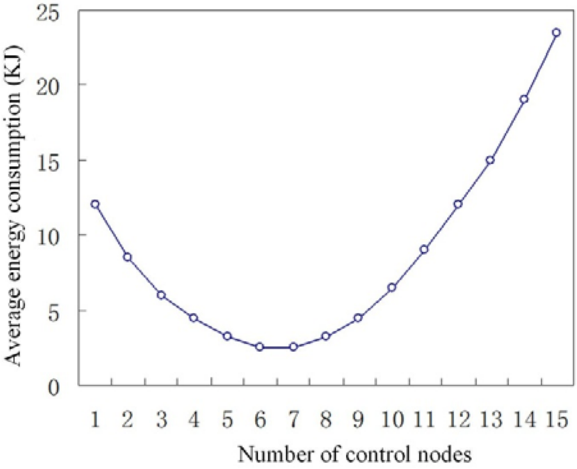

Fig. 3. Average energy consumption of one task running in cloud platform

cloud computing platform, how to determine the number of actual nodes in the coordinated control of traffic that should be opened or closed according to the system structure of cloud platform running and the laws of task arrival, and which control nodes can be opened or closed for the optimizing control of energy consumption will be regarded as the contents of the further study.

4. Conclusion

Aiming at area coordinated control in city road traffic, the real-time traffic information provided by traffic Internet of Things and the correlation relation between different traffic control nodes are used to construct the traffic cloud computing platform meeting the requirements of area coordinated control, so that the control strategies between each intersection of road traffic are uniformly dominated by the cloud computing platform; and at the same time, through strengthening the interactive coordination of traffic Internet of Things technology in acquisition of traffic information, combining the sudden randomness of control task of each node in arriving at the cloud computing platform, and considering the dynamic change characteristic of execution state of control node in road traffic, the cloud strategy model of coordinated control in city road traffic area is established for the analysis of running situation of the cloud computing platform during the multi-node coordinated control from the execution performance and computing power. The experimental result shows that, the cloud strategy in area traffic coordinated control proposed in the Paper guarantees the traffic efficiency of road under the premise of greatly reducing the energy consumption of the cloud computing platform in running.

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