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Research Article

Fog-based Intelligent Transportation System for Traffic Light Optimization

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Abstract: This paper presents fog-based intelligent transportation systems (ITS) architecture for traffic light optimization. Specifically, each intersection consists of traffic lights equipped with a fog node. The roadside unit (RSU) node is deployed to monitor the traffic condition and transmit it to the fog node. The traffic light center (TLC) is used to collect the traffic condition from the fog nodes of all intersections. In this work, two traffic light optimization problems are addressed where each problem will be processed either on fog node or TLC according to their requirements. First, the high latency for the vehicle to decide the dilemma zone is addressed. In the dilemma zone, the vehicle may hesitate whether to accelerate or decelerate that can lead to traffic accidents if the decision is not taken quickly. This first problem is processed on the fog node since it requires a real-time process to accomplish. Second, the proposed architecture aims each intersection aware of its adjacent traffic condition. Thus, the TLC is used to estimate the total incoming number of vehicles based on the gathered information from all fog nodes of each intersection. The results show that the proposed fog-based ITS architecture has better performance in terms of network latency compared to the existing solution in which relies only on TLC.

Keywords: Fog Computing, Reduce Gas Emission, Road Safety, Smart City

1. INTRODUCTION

Intelligent transportation systems (ITS) has been becoming a key aspect to realize the concept of Industry 4.0 and smart city [1, 2]. ITS can bring logistic systems into more efficient. In terms of smart cities, ITS can enhance road safety and lower gas emission [3, 4]. Currently, most ITS architectures are based on cloud computing [5]. In ITS, the network should be reliable and the task should be processed in real-time. Thus, it is still challenging to design an optimal ITS with the current architectures.

Although cloud computing offers some advantages for ITS, its approach naturally conflicts with the principles of ITS. For instance, cloud data centers are generally remote, leading to an unacceptable transmission latency. Alternatively, fog computing can outperform conventional cloud computing, as it brings the cloud closer to the edge (e.g., end-users and devices) to provide low latency and location awareness for the target systems [6, 7]. Therefore, fog computing can be suitable for handling ITS communications and processes [8].

There have been extensive researches on ITS. However, only a few address fog-based ITS architecture. The researchers surveyed the role of big data analytics to improve the efficiency of fog-based ITS [9]. Some researchers proposed a fog-based system for vehicular ad hoc network (VANET) smart mobility applications [10]. The authors in [11] propose the integration between fog and cloud to enhance the performance of IoT applications, such as smart traffic [12]. Different from the mentioned works, in this paper, the authors propose a fog-based architecture to solve traffic light optimization problems.

The first problem is the dilemma zone problem. In this problem, the vehicle is located between the should-go and the should-stop zone. When the vehicle is in this zone, the vehicle may hesitate

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to take action whether to accelerate or decelerate. Furthermore, the vehicle will be more confused when the traffic light is shown a yellow sign and at the same time, the vehicle is in the dilemma zone. This condition may lead to serious traffic accidents. Thus, we consider deploying fog node on each traffic light to overcome this problem. The roadside unit (RSU) node is used to collect the current traffic information (e.g., vehicle's position and vehicle's speed) and transmit it to the fog node. Then, the fog node will estimate and determine the traffic light scheduling based on the gathered information from RSU nodes. Further, they choose fog node to execute this process because it requires to be processed in real-time.

The second problem is to make each intersection able to estimate incoming number of vehicles from its adjacent intersection. We consider the traffic light center (*TLC*) to perform the task of this problem. Specifically, the *TLC* gathers and stores the information such as total number of vehicles that is passing by on each road of intersection from the fog nodes. Then, *TLC* will use these gathered information to estimate the total number of vehicles that will come to the adjacent intersection. Finally, the *TLC* will transmit the estimation results of incoming vehicles to each respected fog node in the adjacent intersection. Therefore, the adjacent intersection aware of the incoming traffic condition.

Based on the explanation above, the role of the fog node in the proposed architecture is to provide a real-time computation process to solve the dilemma zone problem. The *TLC* has similar functionality with the cloud server in which is used to store the global information of the intersection. It makes each intersection aware of the other intersections' traffic conditions. Moreover, it is expected that the proposed method has better performance in terms of network latency compared to the existing solution in which relies only on *TLC*. As for the *TLC*, it is used to estimate the incoming number of vehicles for each intersection. Furthermore, the role of the RSU node is only for providing the current traffic condition. Since the RSU node has a computation constraint, then the collected traffic conditions information will be transmitted and processed on the fog node in which has more capability to conduct the computation process.

2. PROPOSED FOG-BASED ITS ARCHITECTURE

The proposed fog-based architecture consists of three layers which are edge, fog, and cloud layer. The RSU nodes are located in the edge layer. The fog layer comprises traffic lights equipped with a fog node. A fog node can be a switch or router which has an adequate computational capability to perform the task. The Cloud layer, as mentioned above, consists of *TLC*. The wireless communication link is used to connect between the edge and fog layer. The communication between the fog and cloud layer is provided through broadband communication links since it has longer distances. As for the communication between RSU and the vehicle, it could use a vehicle to infrastructure (V2I) communication protocol in which the problem of it is out of this paper scope.

Consider an intersection road that consists of traffic lights such as depicted in Figure 1. These traffic lights are equipped with a fog node. Each traffic light can communicate to the other through a fog node. We assume that the traffic light only able to communicate to each other inside of their domain. The reason lies in the distance between intersections that varies in reality. It thus not feasible to connect each intersection domain by using only fog nodes. Also, the RSU is considered as a node to gather the current zone location and speed of the vehicle. We deploy three RSU nodes (e.g., G-RSU, Y-RSU, R-RSU) on the side road where each node only responsible to monitor its zone. For instance, G-RSU, YRSU, and R-RSU nodes only responsible to gather the traffic information that are located in the should-go, dilemma, and should-stop zone respectively. Furthermore, we also consider *TLC* to connect each of intersection domain. The *TLC* has a similar functionality with the cloud server in which is used to store the global information of the intersection. It makes each intersection aware of the other intersections' traffic conditions. The traffic light scheduling is also implemented by using an algorithm that proposed in our previous work [1].

Second, this paper considers each intersection aware of its adjacent. The *TLC* is used to process the estimation number of incoming vehicles based on the gathered traffic information of the fog node. Then, the estimation results will be transmitted

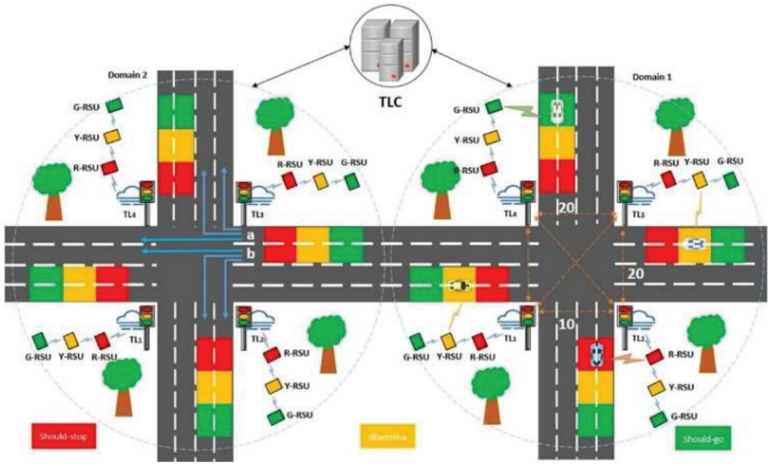

Fig. 1. The architecture of the proposed fog-based ITS for traffic light optimization

to each fog node in the adjacent intersection. Particularly, we assume there are two lanes on the road which are lane a and b. Each vehicle on these lanes may take a left turn, a right turn or a straight forward. The *TLC* table is used to estimate the total vehicle numbers on each lane of the adjacent intersection. Each fog node will transmit the total number of vehicles and store it in the *TLC* table. As shown in Table I, Fog ID, Lane ID, and Number of Vehicles in the *TLC* table represent the location of fog node, lane information, and a number of vehicles in the lane of respected Fog ID. For instance, fog node 3 in Domain 1 is given Fog3-1 as its Fog ID. The lane information of Fog3-1 is denoted by Fog3-1a and Fog3-1b. And the number of vehicles in each lane is stored in the number of vehicles column. This information, later on, will be used to estimate the number of vehicles for the adjacent intersection.

Based on Figure 1. There are a total of 20 vehicles in fog3-1, 20 vehicles in fog4- 1, and 10 vehicles in fog 2-1. Then, it can get a total of 50 vehicles in Domain 1. The *TLC* will estimate the number of vehicles for the adjacent intersection which is located in Domain 2. The process of

Table 1. An example of vehicle information table of TLC

Fog ID	Lane ID	Number of Vehicles
Fog3-1	Fog3-1a	10
Fog3-1	Fog3-1b	10

estimation number can be expressed as Equation (1) and Equation (2)

$$straight\ and\ turning\ right\ = \frac{\frac{20}{2}+20}{20+10+20} = 0.666 \quad (1)$$

$$straight\ and\ turning\ right\ = \frac{\frac{20}{2}+10}{20+10+20} = 0.444 \quad (2)$$

As mentioned above, the total number of vehicles in Domain 1 is 50 vehicles. Then, *TLC* can estimate the current volume of each lane in Fog3-2 as Equation (3) and Equation (4)

$$Estimated\ volume\ in\ Fog3-2a\ = 0.666 * 50 = 30 \quad (3)$$

$$Estimated\ volume\ in\ Fog3-2b\ = 0.444 * 50 = 20 \quad (4)$$

where the *TLC* can estimate the volume of other sections in Domain 2 by using the same mechanism.

3. DELAY ANALYSIS OF FOG-BASED ITS ARCHITECTURE

Taking a situation of intersection road where different total number of vehicles passing by at each section. At first, RSU gathers real-time data based on the current condition of the traffic. Each traffic light waits for the incoming data gathered from the RSU. Then, the data will be processed on the fog node for the traffic light scheduling. There is a condition where the fog node should offload the task to an available node due to the computation storage constraint. In this case, the distributed computing mechanism is needed to avoid congestion on the fog node. It denotes this case as the worst case and is considered as for our future work. Finally, the traffic light optimization results will be transmitted to the *TLC* for the global information of intersection. Therefore, this research illustrates all of these processes as a weighted undirected graph G = (V, E) such as depicted in Figure 2.

In Figure 2, the vertex set of V = {*TL1, TL2, TL3, TL4, TLC*}, where vertex *TLi* and *TLC* denote the fog node in each traffic light of an intersection and *TLC* respectively. Meanwhile, the edge set of *E* = {*eTL1,TL2, ..., eTLi,TLj, eTLj,TLC*}, where each edge *eTLi,TLj* and *eTLj,TLC* represent the wireless communication link among fog nodes and between fog node and *TLC* respectively. The weight of each edge denoted by *WTLi, WTLj* represent the communication latency between fog node *TLi* and fog node *TLj*. The weight of *WTLj , WTLC* denotes the communication latency between fog node *TLj* and *TLC*. Also, *CTLi* and *CTLC* express the computing capacity of each fog node and *TLC* respectively.

From the above scenario, the service latency for processing the traffic light optimization task on each fog node can be derived as Equation (5)

$$\frac{D_{rsu}}{r_{rsu}} + \frac{D_{TLi}}{C_{TLi}} + W_{TLi,TLj} + \frac{D_{TLC}}{r_{TLC}} + W_{TLj,TLC} \quad (5)$$

where $\frac{D_{rsu}}{r_{rsu}}$ denotes communication latency of RSU. $\frac{D_{TLi}}{C_{TLi}}$ denotes the computation latency of the traffic light optimization process on the fog node *TLi*.

Furthermore, this research considers the transmission latency under the stop-and-wait ARQ protocol. In general, the stop-and-wait ARQ protocol is a basic approach to conduct error control in digital communications in which it offers error and flow control during the transmission. Hence, according to [13], the transmission latency of *WTLi,TLj*, and *WTLj*, *TLC* under stop and-wait ARQ protocol can be formulated as Equation (6) and Equation (7).

$$W_{TLi,TLj} = \frac{D_{TLi}}{r_{TLj}} \times \frac{1+P_{eTLi}}{1-P_{eTLi}} \quad (6)$$

$$W_{TLj,TLC} = \frac{D_{TLC}}{r_{TLC}} \times \frac{1+P_{eTLC}}{1-P_{eTLC}} \quad (7)$$

where *DTLi* and *DTLC* denote the task that transmitted to the fog node *TLi* and *TLC* respectively. ri and rc denote the transmission rate of the link *eTLi,TLj* and *eTLj,TLC*. PeTLi and *PeTLC* express the packet error rate of the link *eTLi,TLj* and *eTLj,TLC*.

In summary, it can be denoted the delay of the proposed fog-based ITS architecture as Equation (8) and Equation (9)

$$\frac{D_{rsu}}{r_{rsu}} + \frac{D_{TLi}}{C_{TLi}} + \frac{D_{TLi}\,(1+P_{ei})}{r_{TLi}\,(1+P_{ei})} \quad (8)$$

$$\frac{D_{TLC}}{C_{TLC}} + \frac{D_{TLC}\,(1+P_{ec})}{r_{TLC}\,(1+P_{ec})} \quad (9)$$

4. PERFORMANCE EVALUATION

To verify the proposed fog-based ITS architecture, we evaluated the latency in service from the system model that is shown in Figure 1 by using Equation (9). The simulation parameters and metrics are presented in Table 2. According to [14], the delay between IoT nodes (i.e., RSU) and its corresponding fog node, among fog nodes, and between fog nodes and cloud (i.e., *TLC*) are uniformly distributed

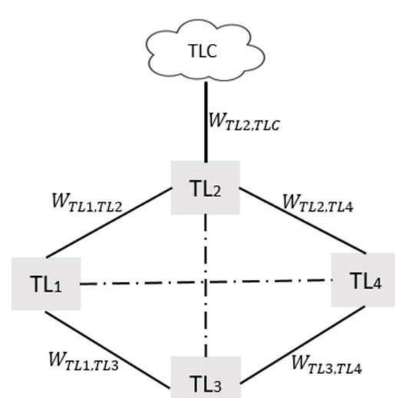

Fig. 2. The weighted undirected graph

between U[1, 2], U[0.5, 1.2], and U[15, 35] ms respectively. Also, it sets 100 Bytes of network length for the task of the first problem, and 500 Bytes for the task of the second problem. This research implemented the proposed fog-based ITS architecture in iFogsim [15] where it is used to describe the network topology and simulate tasks throughout the simulator. The simulation tests were running in the desktop computer equipped with an Intel Core i5-4690 processor, 16 GB of RAM, and Microsoft Windows 10. Furthermore, the researchers tested the proposed fog-based ITS architecture with two different vehicles scenarios which are 30 and 60 cars.

Following in Figure 3, the proposed fog-based ITS architecture can overcome *TLC*-based architecture in terms of latency when it executes the first problem task. There is a correlation between the latency and the number of cars. In conventional *TLC*-based architecture, the latency increased in proportion with the increase of the car's number. However, It is recommended that the proposed *TLC* architecture should be able to maintain the latency when it was subjected to different scenarios.

The proposed fog-based ITS architecture can achieve latency around 14.74 ms even when 30 cars appeared in the simulation scenario. On contrary, the *TLC*-based architecture obtains around 104.43 ms with the 30 cars that have appeared. When the number of vehicles is increased to 60 cars, the fog-based architecture is still able to maintain its network performance with obtained latency of around 15.64 ms. The *TLC*-based architecture achieves 108.32 ms which significantly higher than the fog-based ITS architecture. Similarly, the proposed fog-based ITS architecture can overcome the *TLC*-based architecture when it executes the task of the second problem. The fog-based ITS architecture can achieve better latency in both 30 and 60 cars scenarios compared to the *TLC*-based architecture.

Table 2. Simulation Parameters and Metrics

Parameters	Values
Number of vehicles in each road segment	30 to 60
Number of traffic lights in each intersection	4
Number of fog nodes in each intersection	4
Weight of normal vehicles	1
Weight of heavily-loaded vehicles	2
Weight of should-go zone & should-stop zone	1
Weight of dilemma zone	2
Length of should-go zone	20 *m*
Length of dilemma zone	30 *m*
Latency between RSU & its fog node (*ms*)	U[1,2]
Latency between each fog node (*ms*)	U[0,5,1,2]
Latency between fog node & TLC (*ms*)	U[15,35]

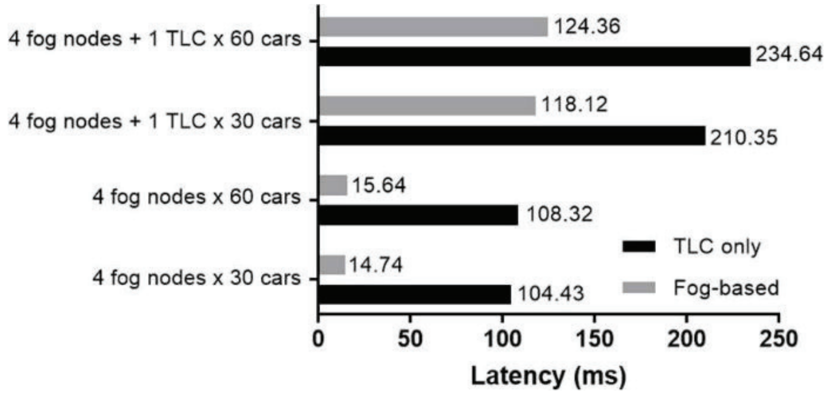

Fig. 3. The latency for executing the first and second problem task

5. CONCLUSION

This research presents a fog-based ITS architecture for traffic light optimization. First, we introduce two traffic light optimization problems that this work wants to tackle. The first problem is executed on the fog node since it requires a real-time process to avoid serious accidents. Then, the estimated number of incoming vehicles is processed in the *TLC*. This is because all of the fog nodes in each intersection can be communicated to the *TLC*. It makes the *TLC* can gather the traffic information of each intersection. Finally, this research verifies the average latency in service of a simulated system by using several scenarios. This research found that the proposed fog-based *ITS* architecture has lower latency compared to the *TLC*-based architecture. In future work, it will analyze the throughput, the operational cost, and the energy consumption of the proposed fog-based ITS architecture. It will also investigate the efficient task distributed mechanism in the worst-case condition such as overcapacity on the fog node.

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7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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