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Cooperative game-theoretic approach to traffic flow optimization for multiple intersections☆

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ABSTRACT

In this study, we focus on optimizing traffic flow at multiple intersections. Particularly, with the development of Internet of Things, intersection controllers are regarded as smart agents which can communicate and coordinate with each other. In this regard, a cooperative game theoretic approach among agents is proposed to improve traffic flow with large network. Thereby, a distributed merge and split algorithm for coalition formation is presented. This algorithm is applied to find out how to incorporate with the cooperation among agents for dynamically controlling traffic light at intersections. Furthermore, we construct a traffic simulation framework to evaluate our approach. With various parameters for traffic density, our proposed system can effectively improve traffic flow in both uniform and non-uniform. In particular, by coordinating among controllers, the waiting time of vehicles at intersections can be reduced from 15% to 25% comparing with previous methods (e.g., Green Wave Coordination).

1. Introduction

The Internet of Things (IoT) spans across many industries, transportation is no exception. The term “Smart Transportation” based-IoT technologies was introduced as a future direction for transportation industry [1]. With increased communication and data collection abilities such as Wireless Sensor Network (WSN), Global Positioning System (GSP), Could Computing, Machine-to-Machine (M2M) and Mobile Devices provide more available data on travel time, origin destination, vehicle volumes and traffic movement. However, the rapid growth of connected objects cause environment becomes more complex and unstable. In this regard, negotiation strategy for cooperating among agents become a hot issues in term of this area [2]. In this work, we take an investigation on how connected objects interact to each other to create a smart environments for transportation industry. Specifically, we take traffic control at multiple Intersections under IoT environment into consider.

Traffic control at intersections is a serious problem, especially in urban areas where traffic volume recently tends to grow drastically. Recently, there have been many methods which focus on this problem. However, since the complexity of traffic control problem, methods in one traffic environment may not be appropriate in another environments. Among various methods, improving the control of traffic flow by using Smart Traffic Light Control (STLC) is the most potential one which can be apply for different traffic environments [3]. The STLC problem involves a number of intersections which cooperate and share their data in order to reduce congestion and improve waiting time of vehicles.

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With the development of advanced vehicle technologies, the term "connected vehicle", which each vehicle is equipped with Internet access, was proposed for improving the ability of sharing data in real time. In our previous works [4,5], we considered to optimize traffic flow in isolated intersection by dynamic traffic light control based on connected vehicle. In particular, we have applied IoT technologies for collecting real time data of traffic flow and based on game theoretic approach for dynamic traffic light system to minimize the waiting time of vehicles in each queue of an intersection. The simulation demonstrates our approach with promising results. However, in reality, there has many consecutive intersections in a small area. An approach for coordinating and communicating among controller agents at intersections is extremely necessary for improving traffic flow, especially in case of high traffic volume.

In this regard, in this work, we propose a new approach to deal with traffic control at multiple intersections by applying negotiation methods for agents which are able to connect to each other based on advanced vehicular technologies. Our contributions include as follows:

- We introduce a new scenario for connected traffic management at intersections which is suitable with the development of smart transportation in near future.
- The proposed approach based on game theory which can be applied for different types of intersections. Moreover, the simulation results show that our proposed system improve effectively traffic flow and reduce congestion, especially in case of high traffic volume.
- Modeling and simulation plays an important role in research, especially in the field of Intelligent Transportation System (ITS) [6–8]. In this study, we develop a framework to accurately represent vehicles, roads and intersections using *Netlogo*, a multi-agent programmable modeling environment.

The rest of this paper is organized as follows. In Section 2, we take a briefly about the background and related works of this research area. In Section 3, we discuss about the modeling architecture of the connected objects at multiple intersections. The cooperative game theoretic algorithm for smart traffic light control is presented in Section 4. In Section 5, we report the experimental results by comparing with previous works. The discussions and future works are concluded in Section 6.

2. Background and related work

2.1. Smart traffic light control

In ITS, STLC at intersections is always a major issues. STLC system is a vehicle traffic control system which combines traditional traffic lights with WSN and Artificial Intelligence (AI). With the way technology has pervaded every part of our lives such as WSN, GPS and so on, there have been many approaches which focus on this research topic. Many works use fuzzy logic to dynamic traffic light control for improving traffic flow at intersection [9,10]. Vehicular Ad Hoc Network (VANET) is a special case of Mobile Ad Hoc Network (MANET) which each vehicle is equipped with wireless and processing capabilities to create a network among vehicles while moving along the road [11]. In this regard, by vehicular communications such as Vehicle to Vehicle and Vehicle to Infrastructure, via signaling processes, the traffic systems are able to control dynamically traffic flow for the most cost effective and efficient.

Traffic control at multiple intersections is always a challenge for researchers and developers since its complexity of geographies. Recently, with the development of intelligent vehicle technologies enable abilities interaction among agents, controller in each intersection is able to coordinate to each other to improve traffic flow in term of large-scale road network. Most literatures focus on dynamic traffic light system to control traffic flow based on Green Wave Coordination to optimize traffic at intersections [12,13]. However, it is needed to put more effort for implementing this approach, especially in case of heavily congested traffic.

2.2. Connected vehicle in IoT environment

Recently, industrial IoT is seen as the next industrial revolution that will introduce the power of connectivity. IoT technologies bring many promises to the industry such as liquid data, visualization, real time data feed, visibility and control capabilities form remote locations [14]. Many applications use IoT technologies to improve our daily life such as smart city, smart home, health-care, energy management and transportations [2].

In the application of IoT technologies for transportation, 'connected vehicles' concept has been identified as the most promising future solution to enhance road traffic conditions and achieve the goal for more efficient and sustainable traffic management solutions [15]. In particular, connected vehicles refer to the wireless connectivity-enabled vehicles that are able to communicate with their internal and external environments such as vehicle-to-sensor (V2S), vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I). By using IoT technologies, each vehicle is regard as a smart object which enable communicate with others. Recently, there have been many studies proposing approaches controlling connected vehicles[16–18]. Moreover, the term 'Social Internet of Vehicle' (SIoV) was introduced which has seen as the next revolution in communication technologies of transportation [19].

2.3. Game theory approach for traffic control

Game theory is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. In term of traffic control at intersection, some algorithms using game theoretic approach, the basic theory of independent and interdependent decision making, has been introduced for intelligent traffic light control problem. Dong and Dai [20] introduces two-person static game model in multi intersections coordinate control problem. Technically, they proposed some concepts of game theory such as Nash equilibrium, mixed Nash equilibrium strategy, Pareto efficiency and Pareto improvement solutions for solving traffic control at multiple intersections problem. Alvarez and Poznyak [21] optimize the congestion of intersection based on game theory which each intersection is regarded as non-cooperative game. Regarding to the non-cooperative game, Dai et al. [22] combines game theory and maximal flow of road network to improve the payoff function of players in game. By this way, the traffic flow can be improved. Recently, in term of connected vehicles environment, Elhenawy et al. [23] apply game theory to introduce an algorithm for controlling autonomous vehicles.

Inspired of connected objects technologies, in our previous works [4,5], we take into account in traffic flow at single intersection. In this regard, we apply algorithmic game theory to make the real-time decision on the time duration of traffic light system to optimize the traffic flow. Specifically, we assume the phases of an intersection (East-West and North-South) as players of the game who want to minimize the waiting time of vehicles in their queue by getting more time duration of green light. In this case, the problem becomes a non-cooperative game with competition between individual players to optimize their utilities. The game has been described as below [4]:

Definition 1 (Non-cooperative game at isolated intersection)**.** A game at an intersection is a negotiation process between two players i and j (which are the phases of intersection). The components for the game G consists of 3 tuples

$$G = \langle P, t, \Pi \rangle \tag{1}$$

where

- P is a set of players (e.g., i and j) which are the phases of intersection. For instance, East-West $\mathcal{EW}$ and North-South $\mathcal{NS}$ of a 4-way intersection,
- t is a set of actions (time durations for green light in each cycle length T) which each player has a list of $t_{i(j)} = \{0 \ldots T\}$ of individual strategies,
- Π: is a function from strategy actions to real-valued payoff function. The payoff function is total number of vehicles in directions of player which can be defined as

  $$\Pi_i(t_i, t_j) = Q_i + t_j\alpha_i - t_i\beta_i \tag{2}$$

  where t_i and t_j are the green-light durations of player i and j, respectively. Q_i is the number of vehicles which are waiting at the phase i. α_i and β_i are the rates of vehicles arriving and departing at phase i, respectively. The arrival rate α of the cycle duration k^{th} is calculated as follows:

  $$\alpha_i^k = \alpha_i^{k-1} + x(\alpha_i^{k-1} - \alpha_i^{k-2}) \tag{3}$$

  where x is the fuzzy parameter $(0 < x < 1)$ which increases when $(\alpha_i^{k-1} - \alpha_i^{k-2})$ increases. Similarity, the departure rate β of the cycle duration k^{th} is calculated as follows:

  $$\beta_i^k = \beta_i^{k-1} + y(\beta_i^{k-1} - \beta_i^{k-2}) \tag{4}$$

A solution to solve the problem, Nash equilibrium, was introduced to analyze the payoffs of each individual players' action. Subsequently, based on the context of Cournot model in game theory, the Nash equilibrium between two players i and j in each cycle length of traffic light system $T = t_i + t_j$ will be occurred at (t_i^*, t_j^*) which can be calculated as

$$t_i^* = \frac{Q_i - Q_j + T\alpha_i + T\beta_j}{\alpha_i + \beta_i + \alpha_j + \beta_j} \tag{5}$$

$$t_j^* = \frac{Q_j - Q_i + T\alpha_j + T\beta_i}{\alpha_i + \beta_i + \alpha_j + \beta_j} \tag{6}$$

subject to

$$t_i^*, t_j^* \in [0, T] \tag{7}$$

where t_i^* and t_j^* are the best responses (Nash equilibrium) of i and j, respectively, by applying Cournot model. Note that, in this work, we assume that the traffic light system includes only two phases which are Green light and Red light. In this regard, the cycle length T is the constant number which is indicated as the time required to display a complete sequence of phases (Green light and Red light).

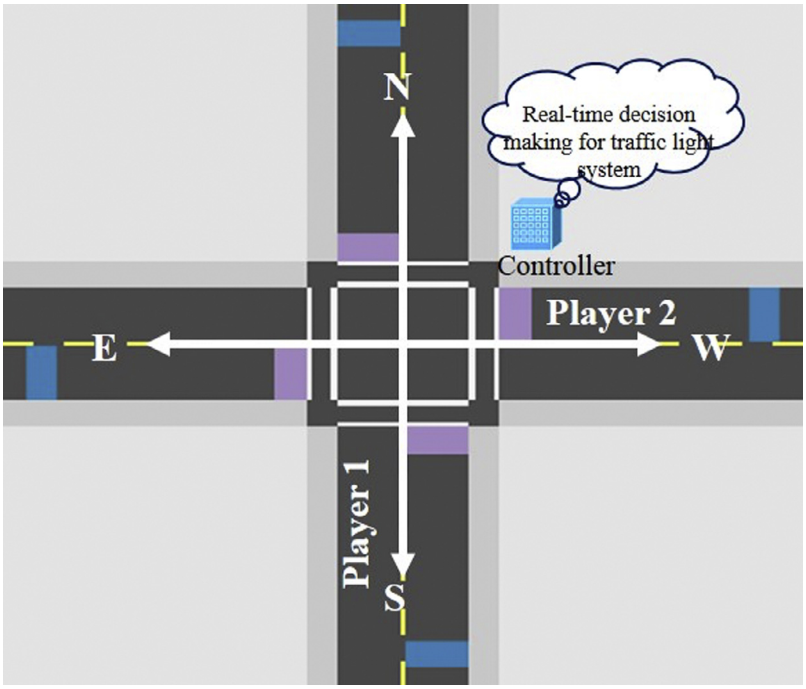

Fig. 1. Game theory for traffic light control at single intersection.

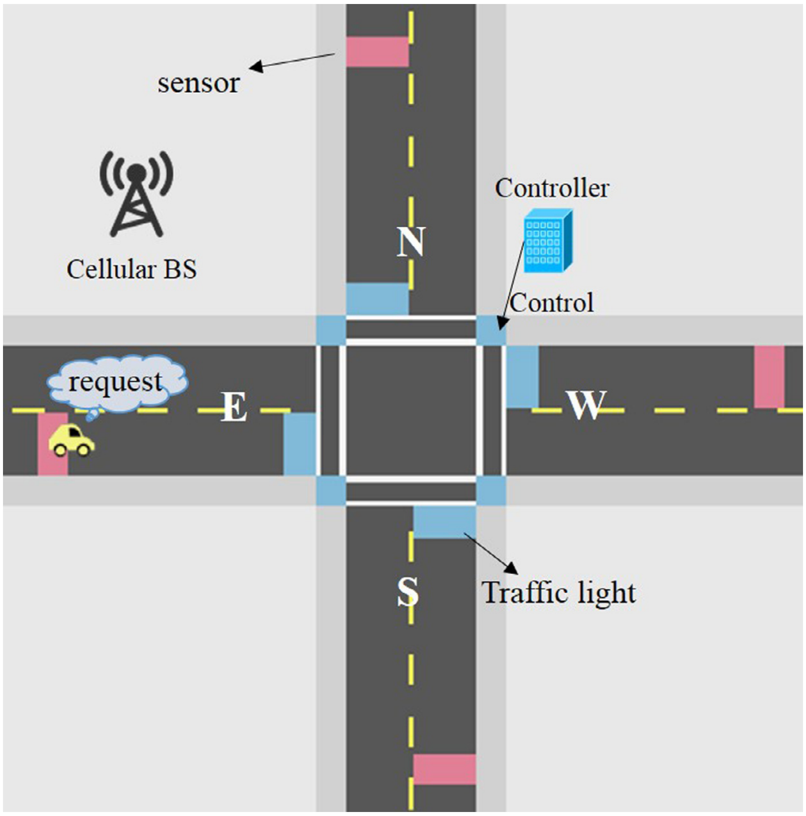

Fig. 2. Connected intersection in IoT environment.

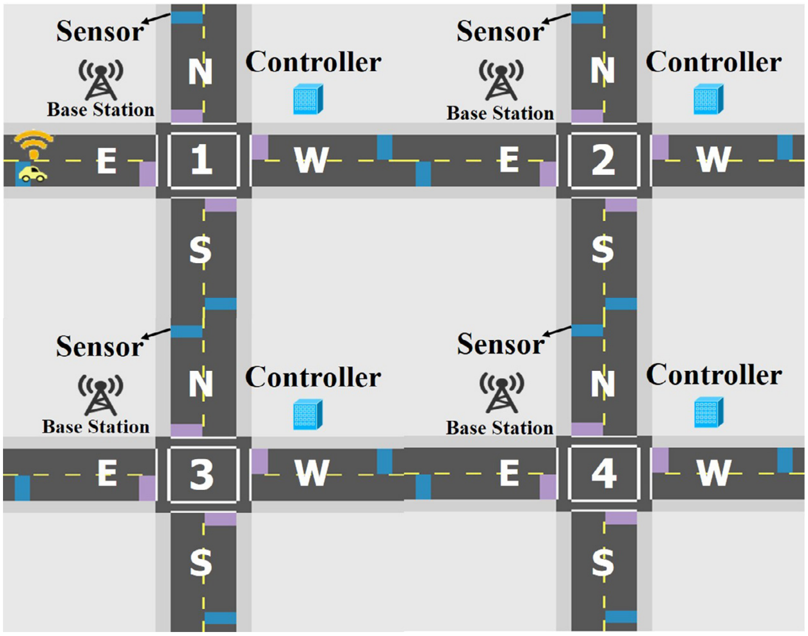

Fig. 3. Multiple intersections in connected environment.

3. Modeling connected objects at multiple intersection

3.1. Connected intersection

Fig. 2 shows an example of connected objects at single intersection. WSNs are deployed on the road to determine when a vehicle arrives, connected vehicles which are equipped sensing devices such as sensors and GPS to communicate with controller via sensing messages. There are some types of messages between vehicles and intersection controllers [24]. In this paper, we use two types of messages that vehicles communicate with controller agent which are *REQUEST* and *COMPLETED*. In particular, when a vehicle arrive intersection, they will send a *REQUEST* message to inform with controller. In other hand, *COMPLETED* message is used when the vehicle has completed its traversal of the intersection.

Algorithm 1 describes the actions of vehicles when they move into an intersection. In particularly, when a vehicle *i* moves into the intersection area, it sends a request message *REQUEST(id, l, d)* which includes ID number of vehicle, arrival lane and destination lane of vehicle to controller agent.

Algorithm 1: Messages types of vehicles to controllers.

Function REQUEST Message
if *vehicle v arrive intersection* **then**
  Send REQUEST(id_v, l_v, d_v) ;
  $Status_v$:= waiting;
end
Function COMPLETED Message
if $pas = True$ **then**
  Send COMPLETE (id_v);
  $Status_v$:= exiting;
end

The *sensing messages* process can be transmitted by supporting of cellular networks (Base Stations) which are located nearby intersection [15]. By this way, controller agent at intersection is able to collect data from all vehicles moving into the intersection and then making decision the dynamic time for traffic lights to improving traffic flow.

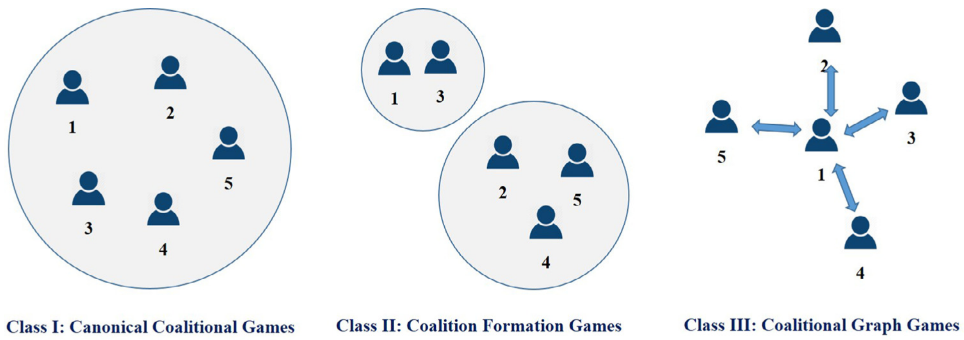

Fig. 4. A novel classification of cooperative games.

3.2. Connected multiple intersections and system model

Fig. 3 shows the connected objects at multiple intersections based on IoT technologies. In this study, we assume that each intersection has four directions which are ($\mathcal{N}$), ($\mathcal{E}$), ($\mathcal{S}$) and ($\mathcal{W}$), and three lanes for vehicles in the incoming direction, which are go-forward ($\mathcal{F}$), turn-right ($\mathcal{R}$) and turn-left ($\mathcal{L}$). They are managed by a controller which is located in each intersection. The controller agents communicate and coordinate with others via wireless network.

In this regard, we propose a cooperative approach among controller agents, through their interactions, to minimize the waiting time of vehicles at intersections based on collecting traffic flow in real-time from connected vehicles. Specifically, we consider a scenario of multiple intersections with M roads. Denote $N = \{1 \ldots M\}$ as the set of all the roads, let controller agent in an intersection $S \subset N$ be a coalition consisting all the roads of that intersection. In case of single intersection, roads in each coalition use non-cooperative game approach to minimize waiting time in their queue as shown in *Definition 1*. When cooperating, controllers form different disjoint coalitions to minimize the waiting time in total network.

4. Cooperative game theoretic algorithms

As we mention above, in this paper, we focus on how to improve traffic flow in the scenario of multiple intersections which is related to reality, especially in urban areas. The idea of the proposed approach based on the cooperative game theory where controller agent in each intersection can be negotiated to each other to make real-time decision for dynamic traffic light system.

In the novel of cooperative game [25], there are 3 types of classifications such as *Canonical Coalitional Games, Coalition Formation Games* and *Coalitional Graph Games* as shown in Fig. 4. A literature coalition game (cooperative game theory) can be defined as follows:

Definition 2 (Coalition game)**.** A coalition game $G(N, \Pi)$ consists of a finite set of players N, called the grand coalition, S is a group of cooperating players ($S \subset N$) and a characteristic function $\Pi : 2^N \rightarrow \mathbb{R}$ is the set of all possible coalitions of players to a set of payments that satisfies $\Pi(\emptyset) = 0$.

In coalition game, no players can do worse by cooperating, i.e., by joining a coalition S than by acting non-cooperatively. This pertains to the mathematical property of *superadditivity* which is defined as:

Definition 3 (Superadditivity)**.** The superadditivity means that the value of a union of disjoint coalitions is no less than the sum of the coalitions' separate values:

$$\begin{aligned} &\Pi(S \cup W) \geq \Pi(S) + \Pi(W) \\ &\text{subject to } \forall S, \forall W \subset N, S \cap W = \oslash \end{aligned} \tag{8}$$

where $\Pi(S)$ and $\Pi(W)$ is the total payoff function of intersection S and W, respectively. In case of cooperation among intersections, an intersection is not only take into consideration to the vehicles that moving in their area but also the vehicles that are moving to their neighboring intersections. For instance, in Fig. 3, when controller in *intersection 1* collect the traffic flow, it also need to take consider the number of vehicles which are moving on the neighboring roads such as ($\mathcal{NE}$), ($\mathcal{WE}$), and ($\mathcal{SE}$) from *intersection 2*. In cooperative model, the utility (payoff) of players in each intersection can be formulated as:

$$\Pi(S \cup W)(t_i, t_j) = Q_i + t_j\alpha_i + t_{j'}\gamma_i - t_i\beta_i \tag{9}$$

where Q_i is the number of vehicles which are waiting at the phase of player i, $t_j\alpha_i$ and $t_i\beta_i$ are numbers of vehicles which are arriving and departing at phase i, respectively. $t_{j'}$ and γ_i are the green light duration and the rate that vehicles arriving phase i from neighboring intersection. Regarding to the cooperative game of intersection controllers, the *canonical coalitional*

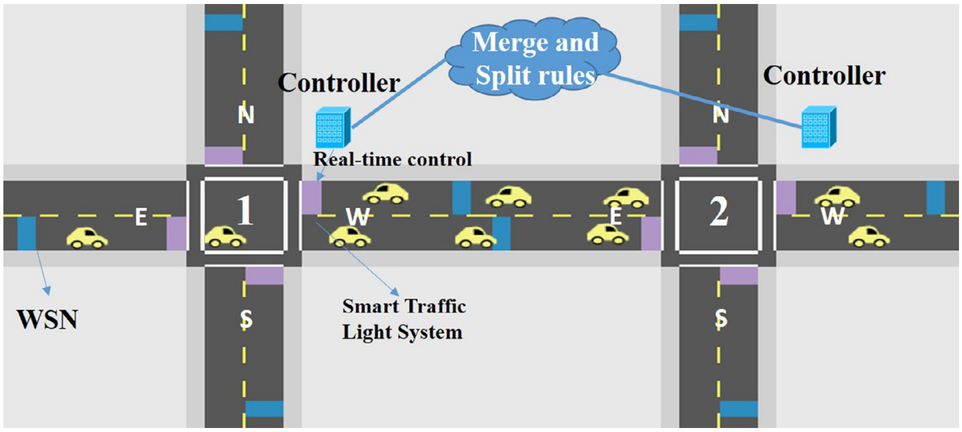

Fig. 5. System model for cooperative game in multiple intersections.

game does not form in this case since the cooperative game for multiple intersections is the *non-superadditivity* which is proved as follows:

Theorem 1. *The multiple-intersections cooperative game with cost is, in general, non-superadditivity.*

Proof: Consider two disjoint coalitions, for instance, S_1 (Intersection 1) and S_4 (Intersection 4) in Fig. 3 where arriving and departing vehicles in roads of an intersection are not influence to other. In this regard, $\Pi(S_1 \cup S_4)(Eq.9) < \Pi(S_1) + \Pi(S_4)(Eq.2)$. Hence, the game is not superadditive.

As result of the non-superadditive of the proposed game of multiple intersections, the *canonical coalitional games* is not form among cooperating intersection controllers. Rather than grand coalition, independent disjoint coalitions is able to form in this scenario. In this regard, we take a novel algorithm for *coalition formation games* into account for the properties of the multiple-intersection cooperative game. In general, in a coalition formation game, the most important aspect is the formation of the coalition in the game. By this way, an algorithm formation for coalition game, referred to as *merge and split* rule was proposed [25]. The basic idea behind the rules is defined as follows:

Definition 4 (Merge and Split Rule)**.** Given a set of players N, any collection of disjoint coalitions S ($S \subset N$) can agree to merge into a single coalition *G* if coalition G is preferred by players over previous state:

$$\sum_{n=1}^{k} \Pi(S_n) < \Pi(\cup_{n=1}^{k} S_n) \quad \text{thus } S_1, S_2 \ldots, S_k \rightarrow \cup_{n=1}^{k} S_n \tag{10}$$

Similarly, a coalition S splits into smaller coalitions if the resulting collection is preferred by the players over S:

$$\Pi(\cup_{n=1}^{k} S_n) < \sum_{n=1}^{k} \Pi(S_n) \quad \text{thus } \cup_{n=1}^{k} S_n \rightarrow S_1, S_2 \ldots, S_k \tag{11}$$

Fig. 5 shows the system model of a cooperative game between two intersections. In this case, the outputs of traffic flow in lane $\mathcal{EW}$ of *intersection 1* (agent 1) and *intersection number 2* (agent 2) are the inputs of traffic flow in lane $\mathcal{EW}$ of *intersection number 2* and *intersection number 1*, respectively. In this regard, *agent 1* and *agent 2* can coordinate to each other to optimize traffic flow in this area. To cooperate, in each cycle time duration of traffic light system, two agents must exchange their data which are traffic densities of each agent. Then, they will make a decision whether they should cooperate or not since as we mention above, the utility for cooperation sometimes is smaller than in the non-cooperative case. For instance, when the traffic flow in $\mathcal{EW}$ lane is low, the non-cooperative case seems like better than cooperative case. The network's initial non-cooperative network, the coalition formation algorithm involves sequential *merge and split rules* . The network's coalition can autonomously decide on whether to perform a merge or split based on the utility evaluation. By applying Nash equilibrium for the game between two players $\mathcal{EW}$ and $\mathcal{NS}$ of each intersection, the time for green light of an intersection in case of cooperative game can be calculated as:

$$t_i^* = \frac{Q_i - Q_j + T\alpha_i + T\gamma_i + T\beta_j}{\alpha_i + \beta_i + \gamma_i + \alpha_j + \beta_j + \gamma_j} \quad \text{subject to } t_i^* \in [0, T] \tag{12}$$

$$t_j^* = \frac{Q_j - Q_i + T\alpha_j + T\gamma_j + T\beta_i}{\alpha_i + \beta_i + \gamma_i + \alpha_j + \beta_j + \gamma_j} \quad \text{subject to } t_j^* \in [0, T] \tag{13}$$

In this framework, a dynamic coalition formation algorithm based on *the merge-and-split rules* can be built. Specifically, if cooperating with neighbor is able to improve the total sum-rate that the involved agent can achieve, then merging occurs. In contrast, if a formed coalition finds out that splitting can improves the total utility achieved by its agent, then a split occurs (Algorithm 2).

Algorithm 2: Trafficlight control at multiple intersection.

Data: $REQUEST\langle id, l, d\rangle$ from vehicles
Result: Real-Time Decision Making for traffic light control in each intersection
initialization;
while *each* Cycle Length T **do**
  Checking REQUEST message;
  Calculating $\sum_{n=1}^{k} \Pi(S_n)$ and $\Pi(\cup_{n=1}^{k} S_n)$;
  if $\Pi(\cup_{n=1}^{k} S_n) < \sum_{n=1}^{k} \Pi(S_n)$ **then**
    Merge Case;
    Calculating Nash equilibrium with the game in each intersection;
    $t_i^* = \dfrac{Q_i - Q_j + T\alpha_i + T\gamma_i + T\beta_j}{\alpha_i + \beta_i + \gamma_i + \alpha_j + \beta_j + \gamma_j}$;
    $t_j^* = \dfrac{Q_j - Q_i + T\alpha_j + T\gamma_j + T\beta_i}{\alpha_i + \beta_i + \gamma_i + \alpha_j + \beta_j + \gamma_j}$;
  else
    Split Case;
    Calculating Nash equilibrium with the game in each intersection;
    $t_i^* = \dfrac{\Gamma_i - \Gamma_j + T\alpha_i + T\beta_j}{\alpha_i + \beta_i + \alpha_j + \beta_j}$;
    $t_j^* = \dfrac{\Gamma_j - \Gamma_i + T\alpha_j + T\beta_i}{\alpha_i + \beta_i + \alpha_j + \beta_j}$;
  end
end

5. Performance evaluation

5.1. Simulation scenarios and parameters setting

In this paper, we consider a simulation area with three intersections. For the experimentation, we try to vary different volume rates of traffic flow to show the effectiveness of our approach in term of waiting time of vehicles and number of vehicles passing intersections in a certain time. Subsequently, two measurement parameters that we take into account in this simulation:

- *Uniform traffic volume*: Two phases East-West ($\mathcal{EW}$) and North-South ($\mathcal{NS}$) have same rate of traffic flow.
- *Non-uniform traffic volume*: Two phases East-West ($\mathcal{EW}$) and North-South ($\mathcal{NS}$) have different rate of traffic flow which the rate of vehicle arriving to phase $\mathcal{EW}$ is three times comparing with phase $\mathcal{NS}$.

For comparison, we also implement two other approaches:

- *Green wave approach*: A green wave occurs when a series of traffic lights are coordinated to allow continuous traffic flow over several intersections in one main direction.
- *Non-cooperative approach* [4]: we compare the proposed approach with our previous work where we optimized traffic flow at single intersection based on non-cooperative game theory between two phases $\mathcal{EW}$ and $\mathcal{NS}$.

In this regard, there are two metrics that we take measure:

- *Waiting time of vehicles*: We calculate the average waiting time of vehicles at intersection ($Status_i$:= WAITING;).
- *Number of Vehicles passing in a certain time*: In a certain time (i.e., 1000 ticks or 2000 ticks), total number of vehicles can pass the simulated area.

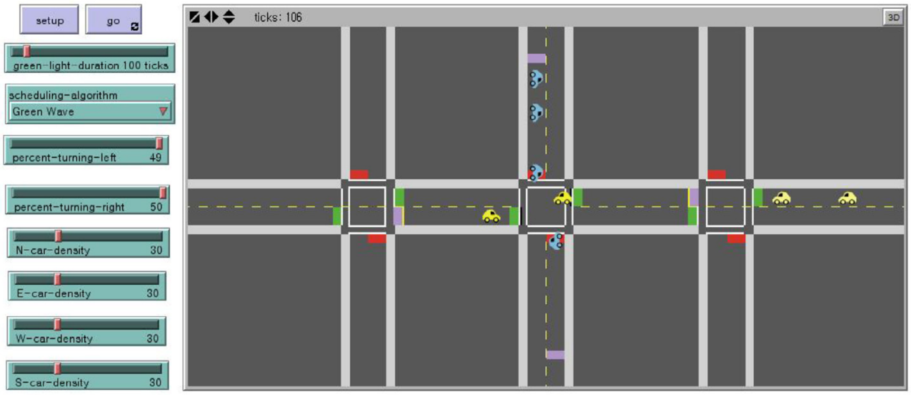

Fig. 6. The interface for the simulation scenario.

Table 1
Simulation parameters.

Parameters	Values
Intersection area	200 × 100 patches
Unit of time	Ticks
Simulation time	10 times per trial
Execute time (per run)	1000 ticks
Speed of vehicle	8–16 patches/10 ticks
Acceleration of vehicle	0.5–2 patches/10 Ticks
Traffic cycle length (T)	200 Ticks
Density of vehicle	10%–60% per each direction

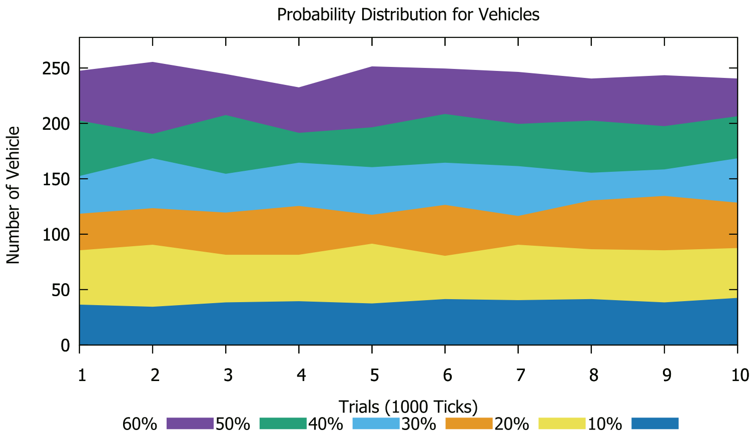

Fig. 7. Number of vehicles appearing at simulated area.

5.2. Modeling and simulation

As we mention, to develop a general IoT environment for smart traffic light control is quite difficult since the heterogeneous possible scenarios. In this paper, we use *Netlogo simulator*, an Agent-Based Modeling environment, for simulating traffic light control at intersections. *NetLogo* is written mostly in *Scala*, with some parts in *Java* and it works well under PC with Intel core i7-4790 CPU 3.6 GHZ and 16GB main memory. Fig. 6 shows the interface of our traffic simulation.

Table 1 shows the parameters that we use for the simulation. In this regards, simulated area with 200*100 patches, the unit of time is *tick*. For the simulation time, we execute *10 times* per implementation to show the variances of each experiment and averaging them as the final results. For the cycle length *T*, the constant value equals 200 ticks. Regarding to traffic volume, instead of using constant number of vehicles arriving at intersections, we take into consider that a vehicle appearing at intersection following probability distribution. In particular, the rate for a vehicle arriving at intersection per *10 ticks* from *10%* to *60%* in each direction. Fig. 7 shows number of vehicles appearing at intersection after 10 times of trials during 1000 ticks of simulation time.

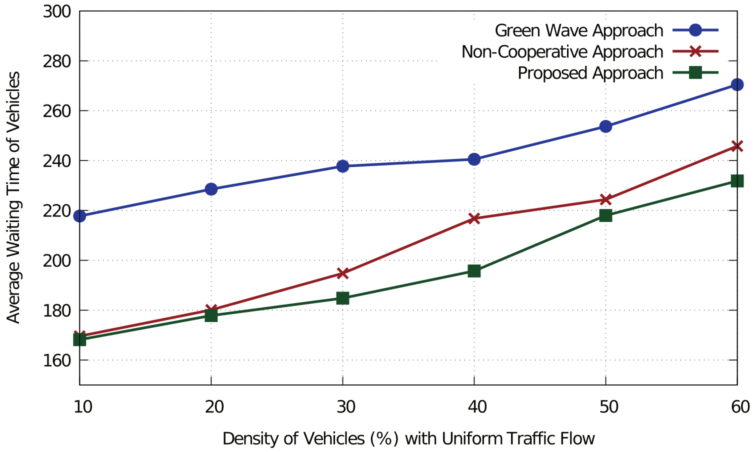

Fig. 8. Average waiting time of vehicles with uniform traffic volume.

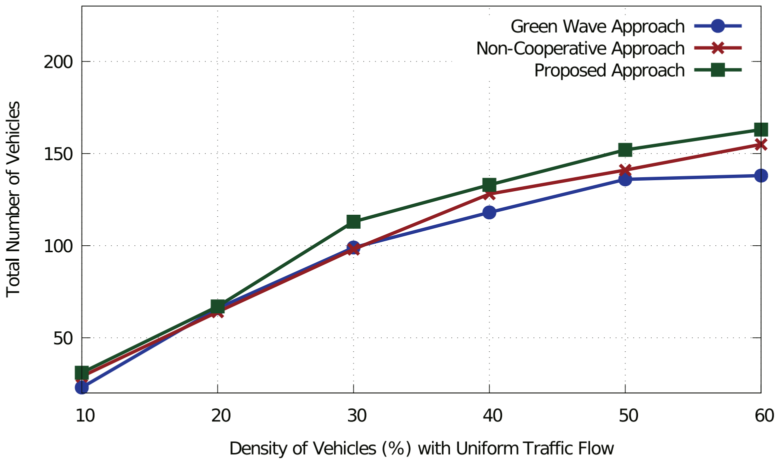

Fig. 9. Total number of vehicles passing intersections with uniform traffic volume.

5.3. Simulation results and analysis

In case of Uniform Traffic Flow, Fig. 8 shows average waiting time of vehicles which following the increasing density of vehicle in each direction. As result, vehicles in Green Wave approach need spend more time to pass intersection, the reason is that in Uniform Traffic Flow, the rate of vehicles arriving intersections is similar, applying green wave approach for one direction will make the vehicles in other directions spend more time for waiting. The simulation results also show that if intersection controllers cooperative to each other will improve traffic flow. For more detail, Fig. 9 demonstrates the result of total vehicles passing the intersections in a same amount of time. In this regard, our approach always get better comparing with previous works, especially in term of high traffic flow when green wave approach have to face with congestion problem.

In the other hand, Figs. 10 and 11 show average waiting time of vehicles and total vehicle passing intersections in term of Non-Uniform Traffic flow, respectively. Green wave approach reaches good performances when the density of vehicles is low, however, it gets worse when we increasing the density of vehicles. By using cooperative approach between intersection controllers, we are able to reduce traffic congestion and improving the waiting time of vehicles at multiple intersection.

6. Conclusion and future work

Connecting Traffic Management System with using the power of analytics is a key to smooth traffic management. The development IoT enables the connectivity for traffic infrastructures which is able to bring the opportunities for smart traffic control in term of large areas. Recently, the rapid growth of vehicles on the road and the limited resources provided by current infrastructures lead to ever increasing traveling times. As the number of road users constantly increases, and resources provided by current infrastructures are limited, intelligent control of traffic will become a very important issue in the future.

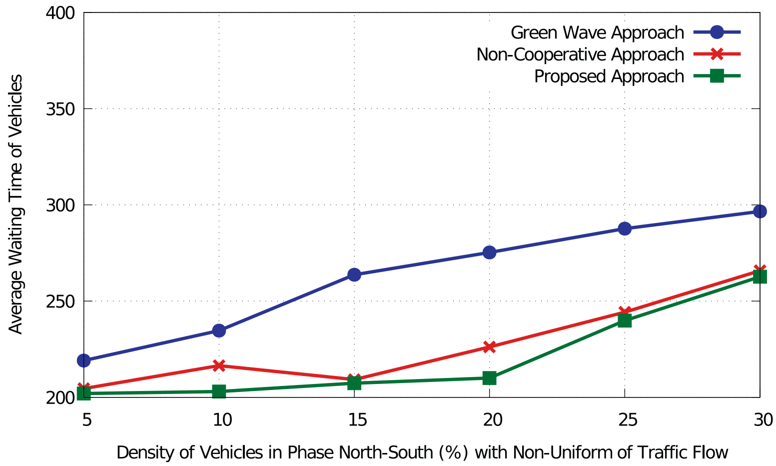

Fig. 10. Avarage waiting time of vehicles with non-uniform traffic volume.

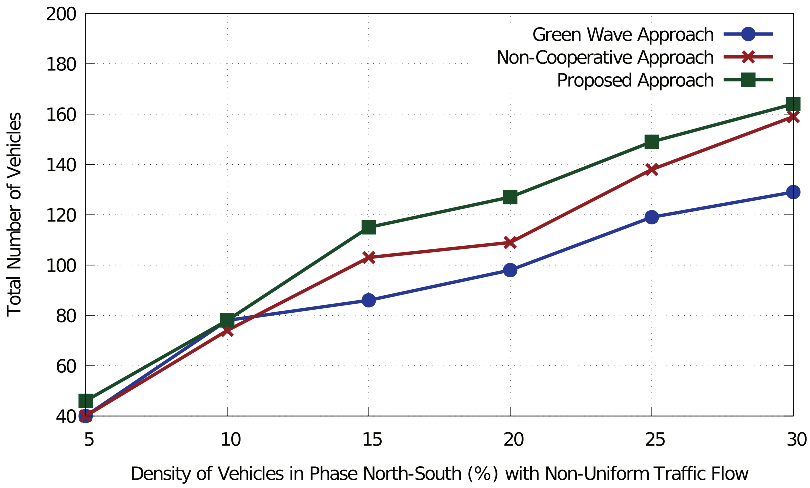

Fig. 11. Total vehicles passing intersections with non-uniform traffic volume.

Transportation research has the goal to optimize traffic flow. In this study, we propose a new approach for traffic control at multiple intersection. In particular, based on advanced vehicles technologies which every object is able to communicate and coordinate with other infrastructures, we consider to apply cooperative game theoretic between agents to optimize their abilities. In this regard, auto-negotiation method between controller agents at intersections can decide whether they should cooperate to improve traffic flow. The simulation results show that our approach achieves potential performance for traffic control at multiple intersections comparing with previous works.

For next steps of this study, to deal with flexible problem which different shapes of intersections, we take into account in a Distributed Traffic Management Approach where each connected vehicles is regard as a player to be able to automatically decide passing the intersection without the permission from controller(traffic light system). Moreover, Social Internet of Vehicles (SIoT) with social relationships among vehicles is also considered to enables executing applications for Smart Transportation.

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