Coordinated traffic lights and auction intersection management in a mixed scenario

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IoT (Internet-of-Things) powered devices can be exploited to connect vehicles to a smart city infrastructure and thus allow vehicles to share their intentions while retrieving contextual information about diverse aspects of urban viability. Such a complex system is aimed at improving our way of living in the city by mitigating the effect of traffic congestion, and consequently stress and pollution. We place ourselves in a transient scenario in which next generation vehicles that are able to communicate with the surrounding infrastructure coexist with traditional vehicles with limited or absent IoT-capabilities. In this work we focus on intersection management and, in particular, on reusing existing traffic lights empowered by a new management systems. We propose an auction based system in which traffic lights are able to exchange contextual information with vehicles and the nearby traffic lights with the aim of reducing average waiting times at intersections and consequently, overall trip times. We evaluate our proposal using the well known MATSim transport simulator, by using a synthetic Manhattan map and a new map we build on an urban area located in our town, in Norther Italy. In such an area, instrumentation through IoT devices has been set up as part of an European research project. Results show that the proposal is better performing than the classical Fixed Time Control system currently adopted for traffic lights, and then auction strategies that do not exploit coordination among nearby traffic lights.

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

Additional Key Words and Phrases: Smart city, Connected vehicles, Intersection management, Vehicle coordination, Auctions

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1 INTRODUCTION

As Smart City initiatives continue to gain momentum worldwide, the integration of advanced technologies and intelligent systems has become instrumental in transforming urban landscapes into sustainable and efficient environments. The advent of the Internet of Things (IoT) [1] and the recent advancements in embedded systems has brought significant benefits to urban viability in Smart Cities, the latter being now able to gather useful information in real-time with regards to traffic, city safety and current events.

We envision a scenario in which in the future only autonomous and connected vehicles will populate the streets and mobility will be smart: vehicles will be able to take decisions about their routes by considering many different aspects such as traffic, the length of the path between origin and destination, the cost of the route, the driver needs, the state of

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current traffic and so on. Smart mobility will be possible thanks to the surrounding smart city infrastructure and will resolve in a reduction of traveling times, traffic congestion, pollution, driver stress and will make cities a better place to live and work. However, to get to this scenario many challenges have to be addressed, such as the best way to make vehicles go through intersections, how to reduce parking search time, how to facilitate left turns, and so on [2].

In this paper we concentrate on the crucial challenge in urban mobility [3] that is intersection management, i.e., how to facilitate and smooth the flow of vehicular traffic going through a crossing. Traditional traffic lights and precedence rules were originally designed considering a situation where vehicles were solely human-driven. Consequently, these mechanisms were devised with consideration for human characteristics and limitations. On the one hand, traffic lights ensure fairness by allowing all vehicles to eventually pass the crossing, following a First-In-First-Out (FIFO) policy for each lane. However, FIFO policies often result in idle vehicles waiting at the intersection when there are no vehicles approaching from the intersecting lanes. On the other hand, precedence rules do not suffer from this problem but may sacrifice fairness. For example, a STOP sign may keep a vehicle idle for a prolonged period if a large number of vehicles with priority continues to arrive. In other words, traffic lights maintain low vehicle latency but are not work conserving, while precedence rules are work conserving but can lead to high latencies for certain vehicles.

In the future scenario where all vehicles are autonomous and connected, more intelligent strategies for crossing management can be implemented, by leveraging real-time data and communication capabilities to optimize intersection management: connected vehicles can exchange information with each other (V2V) and with the infrastructure (V2I), enabling enhanced situational awareness and coordination at intersections [4]. For example, vehicles will not need to come to a complete stop at intersections but might dynamically adjust their velocities to avoid collisions in crossings [5]. By employing such strategies, intersections can be efficiently occupied and managed while optimizing traffic flow and minimizing delays for all vehicles involved. This will improve traffic flow, reduce congestion, and enhance the overall transportation efficiency, security [6], as well as improve emergency management.

Nevertheless, the complete transition from solely human-driven vehicles to fully autonomous and connected ones will not happen overnight, on the contrary, it is a process that will require a considerable amount of time to reach its culmination. During the initial phase of this transition, human-driven non connected vehicles will need to coexist with autonomous and/or connected ones. vehicles, and vehicles with communication capabilities will coexist with vehicles without such capability. This mixed coexistence scenario has been much less studied in literature.

In this paper we place ourselves in the mixed scenario where the distinction between vehicles is determined by their communicative capabilities, and we propose a novel auction-based arbitration strategy for (already existing) traffic lights for crossing management. With respect to our previous proposals [2, 7], here we do not manage each intersection separately, but we coordinate traffic lights that are placed on nearby intersections. The proposed coordinated strategy is then tested against two baselines: a classical Fixed Time Control system and an auction strategy without traffic lights coordination. Validation is done through simulations by using MATSim, an urban mobility simulator that takes inspiration from MAS (Multi Agent System) literature [8]. In MATSim, each road user is modeled as an autonomous agent that feature individual and distinct behaviors. Thus, we are able to model the co-existence of different road users' categories (i.e. connected and non-connected cars) and examining the results as an emergent global behavior obtained through the interaction among all agents. Simulations are carried on two different types of map: an artificial Manhattan style map, and the replicate a one squared kilometer area in the city of Modena (Northern Italy), which has been instrumented with a wide array of smart sensors and communication capabilities in the context of a city project named MASA (Modena Automotive Smart Area). Results show that traffic lights coordination is able to reduce traffic times and is a policy that is suitable for the transition period toward all connected vehicles.

Roadmap. The rest of paper is organized as follow: in Section 2 we discuss Related Works; in Section 3 we describe our proposal for traffic lights management; in Section 4 we present the experiments we performed to validate our proposal, and we report and discuss the obtained results; finally in Section 5 we conclude the paper with some final considerations and description of future works.

2 RELATED WORK

The recent survey by Mariani et al. in [9] addresses many aspects and challenges arising in future smart cities. In particular, authors highlights how coordination among vehicles is a prominent issue in smart cities contexts. Within their classification of coordination problems for connected autonomous vehicles, in this work we focus on *resource oriented* issues, more specifically on traffic flow optimization in traffic-light arbitrated intersections.

There is a body of work that exploits the communication between vehicles and city infrastructure to manage the intersections in urban areas [10] [11] [12]. These proposal, however, assume that all the vehicles are able to communicate either with the smart city infrastructure or among each other. This makes these methods applicable in the future, i.e. when all vehicles will be designed to incorporate communication capabilities and/or advanced driving systems. In contrast, in this paper, we study the impact of the co-existence of both next-generation vehicles with traditional vehicles, and we propose approaches that are able to support both type of vehicles. Such scenario has been addressed also in [13] and [5], here however, we exploit already existing city infrastructure and we take into consideration all vehicles in the lanes and not only the first ones approaching an intersection.

As our proposal addresses traffic lights intersection management, we briefly recall some of the main results in the following section.

2.1 Traffic lights and intersection management

Traditionally, signalized intersections were managed by static and fixed timed traffic lights [14]. On the other hand, in [15] the authors propose a method to coordinate autonomous vehicles and human vehicles through traffic lights considering a First Come First Served policy. A different approach is presented in [16, 17] in which two traffic lights compete with each other to get the highest value of green time. In [2] and in [18] authors propose and evaluate how to exploit traffic lights with auction systems, hence being able to manage traffic at the intersections. Micro-auction is exploited in [19] in a decentralized manner to determine the next signal phase. Reinforcement Learning is adopted in [20] to obtain an optimal bidding strategy. In [21] the goal is to minimize the personal delay of drivers through an auction for green time. In [22] the authors use a second-price marked inspired approach for auctions. The importance of auction is that a driver can define his *Value of Time* (VOT) as in [23] and [24]. But another important aspect is the incentive compatibility as analyzed in [25]. If a driver is not incentivized to adopt the system and to not cheat to get a personal improvement over the overall improvement the performance of the overall system degrades; this aspect is considered in [26] and [27]. In [2] and its evaluation [7] the authors also propose to exploit traffic lights with auction systems, hence being able to manage traffic at the intersections. In our work we extend this concept enabling the coordination within traffic lights in order to obtain a bigger view of the actual traffic situation.

3 OUR PROPOSAL: A TRAFFIC LIGHT COORDINATED SYSTEM

In this work we place ourselves in a smart city scenario in which cities are endorsed with infrastructures that are able to communicate with central servers and vehicles, but in which where there is a mixed situation for what concerns the capabilities of roaming vehicles. In particular, we might have *autonomous* vehicles (i.e., able to drive with little or no human intervention) opposed to *non autonomous* ones (i.e., driven by humans), and *equipped* vehicles (i.e., able to communicate with other vehicles and with city infrastructures) opposed to *non-equipped* ones. Observe that equipped vehicles are not necessarily autonomous, but non autonomous vehicles might use embedded with IoT devices or smartphones to enable communications with city infrastructures. In our scenario, equipped and non-equipped vehicles coexist (either autonomous or non-autonomous). We observe that this coexistence poses some challenges that are not present in a scenario with only connected vehicles: i) the behavior of non-connected vehicles is unpredictable, and in a worst case scenario we can not even expect them to follow to traffic rules; ii) no data can be directly collected from non-connected vehicles, even though some might be collected by exploiting city infrastructures (e.g., sensors or camera to gather their position); iii) communication with non-connected vehicles is possible but in limited form (e.g., traffic lights might still be used to indicate to vehicles/drivers if they are allowed to through the intersection). Therefore, solutions designed for a scenario in which all vehicles have communication capabilities might not work in a mixed scenario and, in the latter, some extra constraints might be added to what vehicles are allowed to do.

To address these challenges, with the goal of improving urban mobility, we propose a new traffic lights management strategy, called *Coordinated System with traffic light management* (Coordinated System for short), that is an auction based system exploiting already present traffic light infrastructures at intersection sites, and is able to handle both equipped and non-equipped vehicles. The Coordinated System presented in this paper extends the auction based traffic light management system presented in [2, 18] (named *Basic System* from now on) by taking into consideration information about other close-by traffic lights.

In the rest of this section we present the main components and aspects of the coordinated system.

3.1 Street maps.

We will assume that there is only one lane on each street, per each direction. We will represent at street maps as graphs: there is a node for each crossroad (also called *intersection*) and a directed edge (called *link* or *lane*) for each street connecting two crossroads, directed as the street sense of travel (there will be two directed edges between two nodes if the steet is two-ways). Thus, we will refer to out-going edges as *out-link*, and to in-going edges as *in-link*.

3.2 Traffic lights.

We assume that only one intersection lane at the time displays the green light, while all the other lanes display the red light: all vehicles stops when the light is red and move when the light is green. The length of the green line is fixed and known *a-priori*. The main difference with traditional traffic light management is that (only) equipped vehicles are able to communicate with the traffic light and will try to get the green light for their lane. We will not allow vehicles of different lanes to be in the crossing at the same time, even if they do not have conflicting trajectories, in order to prevent incidents caused by possibly unpredictable behaviours of non autonomous vehicles.

3.3 Traffic light controller

We re-use traditional traffic lights that are already present in cities and that have been equipped with a *controller* that is run on a physical device placed at the intersection site. This device is able to communicate both with a central server and with the equipped vehicles approaching the intersection, and is able to control the traffic light. Furthermore, we assume that the traffic light controllers communicate with sensors placed along lanes to count the number of vehicles in the lanes. This allows the controller to count non-equipped vehicles, as these cannot announce their presence to the surrounding infrastructure.

3.4 Auctions

Vehicles participate to auctions when they approach an intersection controlled by a traffic light. Their aim is to make their lane win the next green light. Thus, there is an auction at each traffic light for each green light. To define the auction strategy we describe how bids are computed and place, and how the controller states which lane wins the auction.

Vehicle budget. Each equipped vehicle is assigned a trip *budget* and that is used to place bids. It is not the scope of this paper to define how budgets are assigned to vehicles, as this issue is more a administrative/political one: local administrations might decide to assign budget according to drivers conduct, ecological incentives, drivers average Km/yds traveled per year, and so on, or even decide to sell budget.

Vehicle bids. Connected vehicles place bids when approaching intersections controlled by traffic lights. A bid is computed as a vehicle total trip budget divided by the number of traffic lights the vehicle will encounter in its route, starting from the current position to destination. In this way vehicles will never run out of budget, not even if reroutes occur. As non equipped vehicles are not able to communicate with the controller, the system assigns to each such vehicle a default bid calculated as the mean of the bids placed by all equipped vehicles. The presence of non quipped vehicle is detected by exploiting IoT devices (such as smart cameras, for example) at the proximity of intersections.

Auction. In the Coordinated System, traffic lights communicate with nearby traffic lights to share information about bids placed by vehicles. Vehicles approaching a traffic light send their bid to the traffic light controller, together with their complete route to destination. The controller collects these information and sends them to the central server. Then, for each vehicle, the server checks if the vehicle will approach a distinct nearby traffic light. If this is the case, it stores the following information: (i) the next traffic light, (ii) the current link the vehicle is in, (iii) the bid placed at the current traffic light. For non equipped vehicles, the server makes a random guess about the next traffic light, selecting each link with a probability that is proportional to the number of vehicles that selected the link in the past.

To compute winning lane of the auction (i.e., the one that will have a green light), the traffic light controller proceeds in the following way:

(1) sums the bids coming from vehicles in the lanes (including non equipped vehicles default bids), lane by lane;
(2) contacts the central server to retrieve the information about the bids placed by equipped vehicles at the previous intersection (if any). The server sends only the bids of those vehicles that are estimated to be at the intersection within a given time lap. Finally, the controller sums the received bids lane per lane.
(3) sums the bids computed in steps (1) and (2), lane by lane;
(4) sets the green light to the lane with the total highest bid.

To avoid starvation, the controller keeps track of how far back in time each lane got the last green light and, if too far back, it automatically adds a huge bid to the starving lane to force a green light.

3.5 Emergency vehicles

An important issue to consider in the design of smart urban solutions is how to handle emergency vehicles. Emergency vehicles are used by special services, such as police or emergency medical care, and usually benefit from special traffic laws that allow them to act differently form the other vehicles. More specifically, emergency vehicles are allowed to pass through intersections even with a red traffic light. We approach this issue assigning a very high fixed bid to emergency

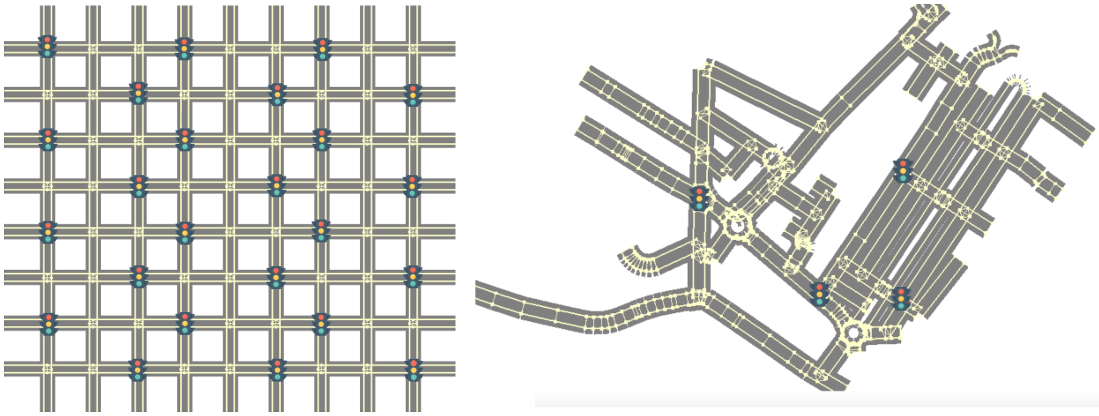

Fig. 1. Maps used in the experiments with location of traffic lights: (left) 8×9 Manhattan; (right) MASA.

vehicles [28]. Thus, it will not be necessary to build *ad-hoc* solutions for such vehicles: emergency vehicles will act as a standard equipped vehicles with a huge budget that is used to "force" the green light on their lanes.

4 EXPERIMENTS AND RESULTS

We performed a large set of experiments using the MATSim simulator to test the effectiveness of the Coordinated System and evaluate if it is actually capable to improve urban viability in a mixed scenario, where equipped and non-equipped vehicles coexist.

4.1 Experimental set up

To test different aspects of the intersection management policy, we used two different map scenarios (a Manhattan style artificial map, and a real city map) and we generated populations composed by vehicles with specific characteristics.

Manhattan scenario. We used the Manhattan style map with eight horizontal links intersecting nine vertical links, for a total of 72 four-way intersections, shown in Figure 1 on the left. Traffic lights have been randomly but evenly placed at 24 of these intersections and regulate all the four links involved. Each link contains two lanes, one per each direction. This is not a real city area map but it is an artificial map in which each intersection has four links, designed to test the algorithms in a very regular scenario.

MASA scenario. The MASA map is the real map of a city area in Modena (Italy) called MASA (Modena Automotive Smart Area), shown in Figure 1 on the right. To import the MASA map in MATSim we used OpenStreetMap[1] and MATim extensions. For our experiments we added three traffic lights, for a total of four traffic lights. Indeed, the original area has only one traffic light and experiments would not have been significant.

We selected this map because it is a 1 KM wide area equipped with several smart sensors that are able to collect urban and traffic data. MASA is a smart city testbed involved in the CLASS HORIZON2020 research project[2] that has been exploited in previous research work to study the behavior of traffic lights [18] and emergency response [29] in smart cities, as in this area, equipped vehicles can already communicate with a central city server trough V2X infrastructure.

[1] https://www.openstreetmap.org/
[2] https://class-project.eu/sites/default/files/class_project_files/class_wetice_2019_roberto_presentation.pdf

Population. Each population defines the total number of vehicles, the number of equipped and non-equipped vehicles for the current experiment. Each vehicle is associated with two locations, one standing for the driver's home and the other one for the driver's workplace, and with a departure time from home and a return time to home from work. Home and work locations are randomly generated on the maps, with the constraint that there must exist a path form home to work and vice-versa (eventually different). Departure and return times are generated according to a normal distributions with peaks at city rush hours (i.e., 09:00AM for departure and 06:00PM for return).

MATSim extensions. To perform our experiments we had to implement new *ad-hoc* functions to extend MATSim. Ideed, even if MATSim has been extensively used in previous researches, its baseline version presents several limitations that we addressed: it does not enable interaction among vehicles and city infrastructure, and it does not contemplate traffic lights. Our implementations are based on previously published MATSim extensions for traffic lights [30] and dynamic agents [31].

4.2 Experiments

To test the proposed Coordinated System we performed several experiments using both maps and varying the number and the type of vehicles in the experiment population. We compare performances of the Coordinated System with those of a baseline given by the Fixed-Time-Controller (FTC) system (simulating the standard traffic lights round-robin-like behavior [14]), the Basic System and a deterministic version of our coordinated system, named Coordinated System - Max.

Basic System. The Basic System works under the same assumptions of the Coordinated System for what concerns the infrastructures at intersections, but the traffic light controller does not communicate with the city server and determine the lane winner of the auction only using the bids of incoming vehicles (i.e., performs only steps (1) and (4) of the coordinated system.) Thus, the main difference with the proposed system is the lack of coordination.

Coordinated System - Max. The Max Coordinated System works in the same way as the Coordinated System with the exception of the guess of the direction that non connected vehicles will take. In this system the guess is deterministic and falls on the next link that have been selected by the majority of the vehicles in the past.

For each experiment, we perform 20 runs and we report the average result of the following metrics (computed for each vehicle):

- *Trip Time*: the total time traveled by a vehicle from departure to destination. It is influenced by the length of the route, by the number of encountered traffic lights and, clearly, the lowest the better.
- *Time to cross*: the time a vehicle spends waiting to go through an intersection with a traffic lights. It is influenced by the number of red lights the vehicle gets and, again, the lowest the better.
- *Green Traffic Lights Ratio*: the ratio between the number of green traffic lights (i.e., no waiting) over the total number of traffic lights incurred to along the route. In this case, the highest the better. For readability, plots will not report results for the FTC system as this ratio is always much smaller than the same value for the other systems, and in a large majority of cases even zero.

Experiment 1. (All equipped). In this experiment the population is composed entirely by equipped vehicles. We progressively increase their number starting from 1,000 up to 5,000, step 500. Results are shown in Figures 2.

We can see that both "Time to cross" and "Trip Time" are better using the Coordinated System in the Manhattan map. Instead, in the MASA map the FTC shows better results. Looking at the "Green Traffic Lights Ratio" our proposal is better than the Basic system on both maps. Eventually, both systems resent the number of vehicles: times increase when increasing the number of vehicles in the scenario, while the Green Lights ratio decreases. The Coordinated System and its deterministic version are comparable, no appreciable difference emerges.

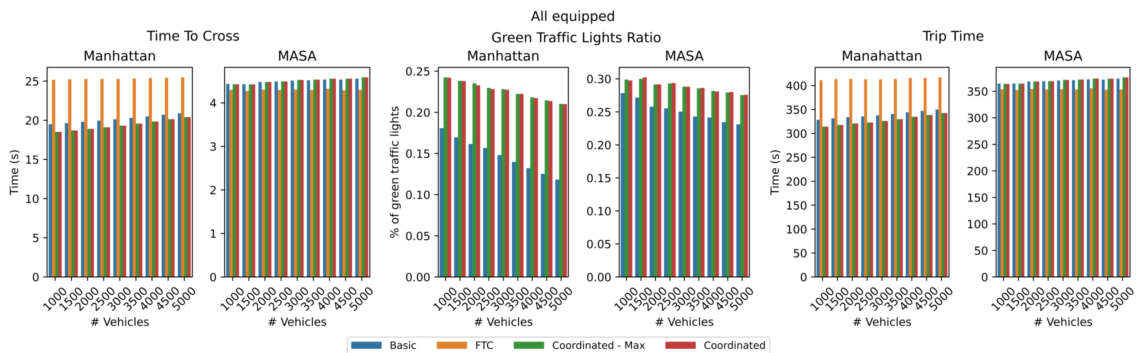

Fig. 2. **Experiment 1.** All equipped

Experiment 2. (Coexistence). In this experiment we progressively increasing the ratio of non-equipped vehicles over the population. In this case the total number of vehicles is fixed to 1,000. We start with 0 non-equipped vehicles and we increase the percentage of non-equipped vehicles by 10% (i.e., 100) in each successive populations, up to 100%. Figures 3 shows the mean of waiting times.

We observe that both "Time to cross" and "Trip Time" are better in our proposal with respect to the FTC but the Basic system shows better results in the MASA scenario. Here, time does not seem to be influenced by the variable number of equipped vehicles. The Green Lights ratio shows better results in our system and, interestingly, does not degrade with the increasing number of non equipped vehicles. On The contrary of what happens in the Basic System, in which the degradation is more evident especially in the Manhattan maps, having a larger number of traffic lights. Again, the

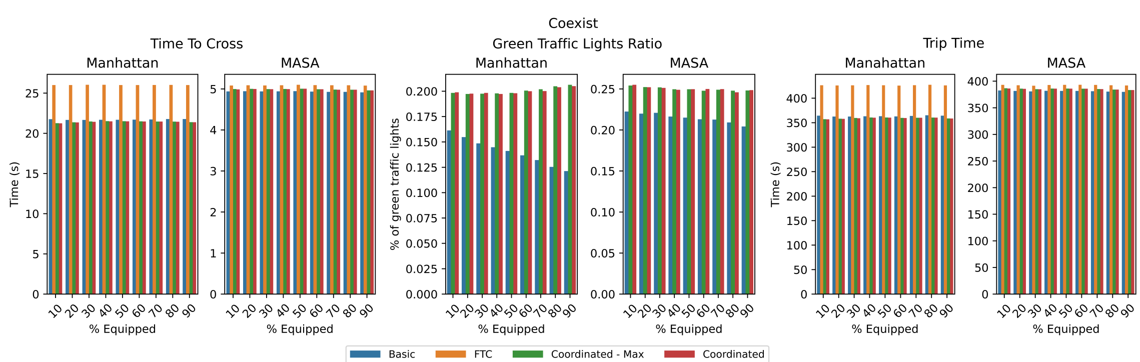

Fig. 3. **Experiment 2.** Coexistence of equipped and non-equipped vehicles

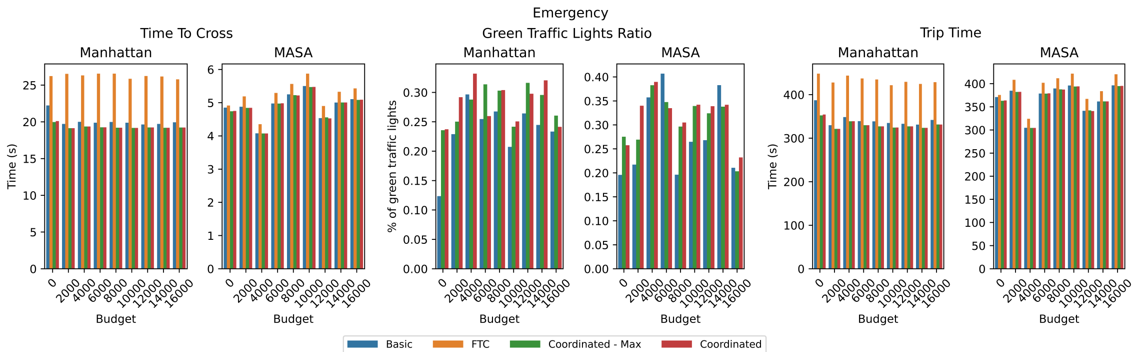

Fig. 4. **Experiment 3.** Emergency vehicles, increasing budget

Coordinated System and its deterministic version are comparable, we observe a slight improvement of the former with respect to the "Green Lights Ratio" in the Manhattan map when the percentage of equipped vehicles increases.

Experiment 3. (Emergency vehicles). In this experiment we test whether the coordinated system is able to privilege emergency vehicles, by only assigning them a very high budget, and to compare its performances with the basic system.

Experiments are conduced on a population of 1,000 equipped vehicles and exactly one emergency vehicle: we selected a random equipped vehicle and we gradually increased its budget (from 0 to 16,000, step 2000). Results shown in Figures 4 are referred to the emergency vehicle only.

Results are then analyzed in order to understand how to set appropriate budgets for emergency vehicles.

We Observe that the coordinated system shows better "Time to cross" and "Trip Time" in all situations. In the MASA map, the difference between the times with the Basic system is lower than in the Manhattan map. The "Green Traffic Lights Ratio" in most case are better for our system but in some cases, the Basic system shows better results (e.g., the two peaks using the MASA map for budget 5K and 12K). It is interesting to note that increasing the budget of the emergency vehicle seems to not increase the performance: in the Manhattan map there is a little improvement of the trip time from 0 to 2000 (and this range will be object to investigation in future works). In the MASA map, there is not a clear trend with respect to the budget increase.

The Coordinated System and its deterministic version are comparable, again, for what concerns "Trip Time" and "Time to Cross", while the situation is fuzzier for the "Green Traffic Lights Ratio" where we can observe that none of the strategies is always (or more often) better than the other. However, these differences does not reflect in a reduction of traffic times.

4.3 Discussion

Experiment results show that urban mobility might benefit from the use of the proposed coordinated system. In particular, in scenarios with a large number of traffic lights and larger percentages of connected vehicles, and with respect to a non coordinated auction system and the standard FTC system.

Indeed, results are better on the Manhattan map having many more traffic lights than the MASA map. In the latter, other factors, other than coordinated auctions at traffic lights, are more relevant to determine trip times. This results is definitively reasonable (a little coordination is not able to resolve traffic flow issues) and endorse the fact that the coordinated system actually works (important enough coordination is able to reduce time in traffic). Moreover, as the percentage of connected vehicles increase, we observe an improvement of time in traffic. Indeed, the more vehicles joining the coordinated system, the more trip data are available and the more robust statistics became. This result shows that the coordinated system is a good choice for the transient period as it will gradually improve urban mobility as the number of non connected vehicles will naturally decrease, and can be a good incentive to the transition to equipped vehicles. On top of this, as the reduction of trip time is also a consequence of the increase of the number of green traffic lights encountered along trips (also with respect to the Basic System), there is an improvement also from the drivers point of view (less stress) and environment (less pollution).

We also observe that performance degrades when increasing the number of vehicles, in both maps. This negative result, however, is intrinsic in heavy traffic situations: no system would be able to be resilient to an indiscriminate increase of the number of vehicles.

It is unexpected, on the other hand, that the guess strategy to forecast the next link of non connected vehicles does not seem to be determinant. The performances of the two strategies (random and deterministic) do not show sensible differences. Results suggests that non connected vehicles traveling on main streets induce an intrinsic distribution that is a good approximation of the one used by our proposed coordinated system. This result will be further investigated to be better understood.

Finally, for what concerns emergency vehicles, increases of budgets do not resolve in improvement of traffic time when the budget is already high, especially when there are many traffic lights (as in the Manhattan map). This might be explained by observing that, even with a high budget, the emergency vehicle alone is not able to free upcoming links if vehicles are lined up due to another traffic light. On the other side, if there are less traffic light, once the emergency vehicle frees its lane the other vehicles disperse more easily and the situation is more variable (as in the MASA map). Also this result will be study of further investigation in order to understand how and if emergency vehicles performances can be improved.

5 CONCLUSIONS

In this work we focused on a scenario of coexistence of connected vehicles and non-connected vehicles in a smart city and on the problem of intersection management. We have proposed an auction based coordinated system to manage intersections that takes into consideration both connected and not connected vehicles. Our proposal has been tested through extensive simulations. Results are encouraging, as they show that the coordinated system is competitive with respect to the non coordinated auction based system and definitely better than the FCT system. Moreover, performances of the coordinated improve when increasing the percentage of connected vehicles, making this proposal suitable for the transient period, as well as its adoption an incentive to transit to connected vehicles.

Future works include deeper analysis of some of the presented results, to understand if the proposal might be improved or if there are some intrinsic limitations (e.g., emergency vehicles management). Moreover, we will investigate if increasing the number of traffic lights that are coordinated might bring further improvements to traffic flows and traffic times.

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