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Decentralized traffic control and management with intelligent vehicles*

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Decentralized traffic control and management with intelligent vehicles

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Contents

Abstract

Traffic congestion in highway network is one of the main issues to be addressed by today's traffic management schemes. Further, automation combined with the increasing market penetration of on-line communication, navigation, and advanced driver assistance systems will ultimately result in intelligent vehicle highway systems that offer solutions to the traffic congestion problem and also improve the capacity without building new highways. This paper presents the results of a survey on Intelligent Vehicles (IV) and IV-based control measures which can provide an opportunity for integration within an intelligent roadside infrastructure, and can be used to improve the efficiency, performance, and throughput of traffic flow. We also describe the existing control designs in connection with (IV-based) traffic management and especially focus on model predictive control methods. Building upon our survey results, we also propose a control design framework that uses the selected IV control measures in a decentralized roadside/vehicle traffic management structure. We conclude by pointing out several open issues and possible solution approaches.

Keywords

Traffic management, traffic networks, intelligent vehicles, distributed control, large-scale systems, model predictive control

1 Introduction

Life betterment, convenience and safety of human life serves as the bottom-line for many scientific and technological innovations. Right from our home to the work place, these technologies try to make life easier and comfortable. Likewise, traveling to and from the work place is one of the inevitable tasks of our daily routine. Although we have well-planned road management schemes, sufficient infrastructure for transportation, and traffic conditions for safe driving, we still face the problem of traffic congestion owing to the ever-increasing traffic demand, which in turn results in loss of time, fuel, and money. Construction of additional highways can be considered as one of the solutions for traffic congestion problem, but it is less feasible due to political and environmental concerns. Another alternative for traffic congestion problem is efficient use of existing infrastructure. This will be the approach taken in this paper.

In the early 90's, the enhancements in the field of communication, control and information sciences provoked the need for better utilization of existing technologies Jurgen (1991). This motivated the basis for integration of these technologies with the existing transportation infrastructure system. It also marked the emergence of a new paradigm for transportation/technology infrastructure coined as "Intelligent Transportation Systems" (ITS) or "Intelligent Vehicle Highway Systems" (IVHS) (Sussman (1993)). IVHS incorporate intelligence in both roadways and vehicles with the intention of reducing congestion and environmental degradation, ameliorating safety and convenience, and maximizing the use of existing transportation facilities. IVHS has six main functional areas:

- Advanced traffic management systems
- Advanced traveler information systems
- Commercial vehicle operations
- Advanced vehicle control systems
- Advanced public transportation systems
- Advanced rural transportation systems

The approach we propose in this paper develops control and management methods that integrate the existing in-vehicle telematics to substantially improve traffic performance in terms of safety, throughput, reliability, environment, and robustness. As a first step towards this goal, we present in this paper the results of the literature survey on IVs and model predictive control. More specifically, in Section 2 we define IV systems, and discuss the IV-based control measures. In Section 3, we discuss model predictive control followed by the control structures that can be implemented for large-scale systems. In Section 4, we present the PATH IVHS control system framework. In the later part of this section, we propose a control framework that uses IV-based control measures in a decentralized roadside/vehicle traffic management structure and we also list several open issues in the proposed framework and possible solution approaches.

2 Intelligent Vehicles and Traffic Control

2.1 Intelligent vehicles

Intelligent Vehicles, a component of IVHS, is considered as a next era for obtaining more efficient driver-vehicle operation. By this, we mean improved safety, operational efficiency, and convenience while driving (Bishop (2005b)). An IV system senses the environment around the vehicle in a highway system and strives to achieve more efficient vehicle operation either by assisting the driver (advisory/warning) or take complete control of the vehicle (vehicle automation). We find its application in all types of road vehicles such as cars, public transport and trucks. IV technologies empower us to control the IV systems by lateral, longitudinal or integrated control systems (Bishop (2005a)).

The lateral sensing systems as the name indicates, assist drivers in monitoring and controlling the side ways/lateral movements of the vehicle. Applications which use this system are lane departure warning system, lane change assist and parallel parking assist systems.

The longitudinal sensing and control systems mainly help drivers in controlling relative velocity between the predecessor and controlled vehicle, forward and rear movement of the vehicle, and maintaining safe inter-vehicle distance. Adaptive Cruise Control (ACC), forward collision warning systems, and Intelligent Speed Adaptation (ISA) are applications among them.

Also, we can divide IV application areas into three categories depending on the level of control:

- Advisory systems provide an advisory/warning to the driver. Examples are blind spot warning, and drowsy driver monitoring
- Semi-autonomous systems take partial control of the vehicle. This control level assists the driver in case of an emergency situation such as collision avoidance. Examples are ACC, precision docking, and precise maneuvering
- Fully autonomous systems take full control of vehicle operation. Examples are autonomous driving, and platooning

2.2 Traffic flow and IV control measures

The traffic flow volume on IVHS can be highly improved by applying full automation (Varaiya (1993)). In this paper, we will also consider fully autonomous control of IV systems. The traffic flow can be increased by decreasing the inter-vehicle spacing between the vehicles and increasing the velocity (Kanaris et al. (1997)). However, there exist certain bounds on these measures.

If there occurs a sudden slow-down in the flow of vehicles due to bad weather conditions, accidents or lane closures, then inter-vehicle spacing among the vehicles will become very low and there may be danger of collision among vehicles causing damage to vehicles. In such cases, safety and comfort factors of the drivers should also be addressed. We can ensure safety among the vehicles by maintaining a minimum, and safe inter-vehicle distance. Moreover, for driver comfort, the jerk produced by vehicle acceleration or deceleration must not exceed 0.1 g (Kanaris et al. (1997)).

With respect to velocity, when there are no vehicles in front of the controlled vehicle, then the vehicle will use the velocity specified by a traffic controller.

An additional way to further improve traffic flow and safety of the current transportation systems is by applying automation and intelligent control methods to roadside and vehicles. This gave rise to the Automated Highway Systems which enable the roadside and vehicles to be treated as a single system. When vehicles are allowed to share information among them, then IV systems can be implemented using *autonomous vehicles* (vehicle-vehicle based systems). Another possibility is to take the advantages of communication systems such as Global Positioning Systems (GPS), digital road maps and wireless communication techniques, and use them for exchanging and sharing information among IV systems and infrastructure in order to achieve proper coordination among their actions. IV system implemented in this way are termed *cooperative systems* (vehicle-roadside based systems).

The focus of our approach is mainly to integrate the intelligence of roadside infrastructure and IV systems with automation. The basic unit for implementing automation in the system is by arranging vehicles in a group termed as "platoon". Hence, we carried out a survey on IV technologies' which support and improve automation concept by allowing vehicle-vehicle and vehicle-roadside communication. Here, we will discuss about the functional areas of IV systems which was found to be apt for our objective:

- Platooning
- Dynamic route guidance
- Cooperative ACC
- ISA
- Cooperative ACC and ISA

2.2.1 Platooning

A "platoon" is a swarm or group of vehicles with a certain size, which are able to communicate with each other for the coordination among their activities. By platooning concept, we can maintain high-speed and short distance among vehicles (Li & Ioannou (2004); Varaiya (1993)). By this concept, more number of cars can be served on the network, which in turn increases the traffic capacity. In a platoon, for safety reasons, spacing with in a platoon (intra-platoon) is kept very small and the inter-platoon spacing is kept larger. Inter-vehicle distance is a key factor which affects the traffic flow. If the vehicle parameters are allowed to be exchanged among the vehicles in a platoon, then vehicle distances can be controlled more closely.

Platooning allows smooth merging, lane changing and splitting maneuvers and maintaining a close inter-vehicle distance among vehicles.

2.2.2 Dynamic route guidance

Nowadays, many individual vehicle are equipped with a route guidance or navigation system. Generally, a route guidance system advises a driver with the "best" route he can take to reach his requested destination (Watling & van Vuren (1993)). This mainly depends on the vehicle's current location. Using a GPS, we can precisely determine the vehicle's position. This information can be looked up in a digital road map. Also the coordinates of the requested destination can be retrieved from GPS database. The digital map can then be used to determine the possible routes to reach the destination

Possible routes to the destination may be calculated within the equipped vehicle or communicated to the vehicle from the local traffic center. When the possible routes are computed based on the average or expected conditions such as geographical locations and road maps, then this scheme is referred as static route guidance system. If the existing traffic conditions such as traffic jams, dynamic speed limits are taken into account while computing the route recommendations, then it is termed as Dynamic route guidance system. In our approach, we are interested in the interaction of roadside infrastructure with the route planning system.

2.2.3 Cooperative ACC

When the vehicle maintains its speed as selected by the driver without considering the environment, then this is called a conventional cruise control system. An ACC system extends the conventional cruise control system, senses the immediate vehicle ahead on the lane, and adjusts the speed of the controlled vehicle to maintain a safe inter-vehicle distance for avoiding collisions (Davis (2004); Darbha & Rajagopal (1999)). There are many variations of ACC. High-speed ACC and low-speed ACC (Stop-and-Go ACC) are popular among them. Though ACC vehicles are able to handle many traffic situations reliably, there exists some adverse traffic conditions such as short-headway cut-ins or sudden and strong deceleration of the upfront vehicle, which it find difficult to handle. Cooperative ACC is a further enhancement of ACC systems. In addition to maintain a safe inter-vehicle distance, IV systems can exchange information about their current speed, position, braking maneuvers and acceleration via wireless technologies. With these vehicle parameters, we can have a tighter control over inter-vehicle distances which in turn ensures safety on the highways.

2.2.4 ISA

ISA combines existing technologies such as GPS and road maps, and adds the legal speed limit to the digital road map, so that each vehicle is "aware" of the maximum legal speed limit prescribed on that road (Thomas (2003)). The legal speed limits may be from a static database or computed by the traffic control center based on the current traffic conditions. ISA also gives feedback to the driver in an advisory, supportive or mandatory manner, when he tries to exceed this legal limit. Advisory systems only give a warning (visually or via sound). Supportive systems decrease the possibility of speeding by increasing the resistance of the accelerator pedal. This system can be turned on and off by the driver. Mandatory systems does not allow a driver to exceed the speed limit and are always turned on. In our approach, we will not only use legal speed limit but also control this speed limit.

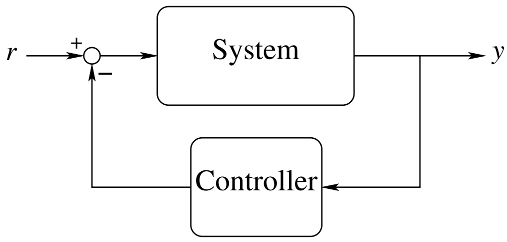

Figure 1: Feedback control problem

2.2.5 Cooperative ACC and ISA

Once the vehicle is equipped with an automatic speed control device, we can integrate other possible options in it. Now, it sounds quite practical and logical to take the advantage of combining Cooperative ACC and ISA systems. In addition to the exchange of vehicle parameters and maintenance of safe inter-vehicle distance, we can then also adjust the preset driving speed automatically to the legal speed limit prevailing on that road (provided by ISA technology).

We will combine all these IV-based control measures in our approach. Having discussed the measures and handles offered by the IV systems, we will now move on to discuss about the methods that helps in controlling the IV-based traffic network.

3 Model Predictive Control

3.1 Definition of the control problem

The control problem (shown in Figure 1) represents the problem of determining the optimal control actions such that the system approaches the desired behavior.

In a **traffic context**, the system represents the traffic network. The traffic sensors or loop detectors measure the current traffic characteristics such as speed, flow, and density. These are the measurable outputs from the traffic system. These measurements are required for determining suitable control actions. *Control actions* are variables which steer the system to achieve this task. The main goal of any successful controller is to determine the control actions that help in maintaining the system behavior as close as possible to its desirable task without violating the constraints. The constraints model the dynamics of the system and its operating requirements. However in practice, there exists different alternative control actions which satisfy the controller's objective. Thus, there is a need to make a selection among the various admissible control actions. This control problem would be solved using the criterion function (also known as performance index) according to which the system behavior has to be evaluated.

Traffic signals, dynamic route guidance, speed limits, ISA, variable message signs, and ramp metering are some examples of the control actions that can be applied to the traffic system. The traffic controller determines these control actions by optimizing certain traffic criterion function such as minimizing the total time spent in a traffic network, the distance traveled, the fuel consumption by a vehicle, maximizing safety or maximizing the throughput and also satisfying the traffic constraints such as maintaining minimum queue length on on-ramps, using existing traffic network and capacity effectively and efficiently, and so on.

Thus, the reaction of the traffic networks to these new control actions are measured by traffic sensors again. A feedback strategy is implied to estimate the deviation of the system from its desired behavior and this estimate is used by the traffic controller to obtain an apt control actions.

Many control methods such as feedback control, optimal control, and model predictive control method are available and can be used for controlling the traffic system (Tsugawa (1999); Kotsialos et al. (2002); Bellemans (2003); Hegyi (2004)).

Using PID, static feedback control methods (Karaaslan et al. (1991)), we take measurements from the traffic system and we use a controller to determine the control actions based on the current state of the system. By this strategy, we can substantially improve the performance of the traffic network. But, such a controller does not predict or consider the future states of the network. This fact is considered as a major drawback of this control scheme because the control actions which seem to improve the current situation, might have a negative impact on the future traffic conditions.

Another approach is the optimal control method (Kotsialos et al. (2002)) which assumes that the future demand and boundary conditions of the traffic network are known in advance. Based on this assumption, the controller calculates the control actions that minimize the objective function. Though this approach considers an assumed future demand, we cannot make this assumption beforehand on a traffic network, as it possess unpredictable behaviors and disturbances. However, often the future demand can be estimated reasonably upstream and downstream measurements in combination with historical data. Optimal control is essentially an open loop control approach and thus suffers from disturbances and model mismatch.

Another alternative is model predictive control (MPC). Many industrial applications have found MPC to be a useful strategy and implemented this technology for controlling processes successfully (Qin & Badgwell (1997)).

In the following section, we will focus on the model predictive controller and its suitability for traffic networks.

3.2 Model predictive control

MPC also known as the rolling horizon approach or receding horizon control is one among the feedback control algorithms that can handle constrained, complex dynamic systems (Maciejowski (2002)).

MPC is a *model*-based controller, solves an open-loop optimal control problem over a finite time interval subjected to system dynamics and constraints. A simple MPC scheme is shown as follows (see also Figure 2).

The controller uses the measurement of current system state and predicts the behavior of the system using an explicit model over a time interval referred as prediction horizon. It solves an open-loop optimal control problem over a control horizon and finds the sequence of control inputs. Since the prediction model cannot replace the real system behavior over an infinite horizons, we cannot use the open-loop manipulated variables for the entire procedure. Hence, a closed-loop strategy is implemented using the receding horizon approach. This is done by applying the present time step optimal control sequence to the system. At every sampling step, we shift the prediction horizon one

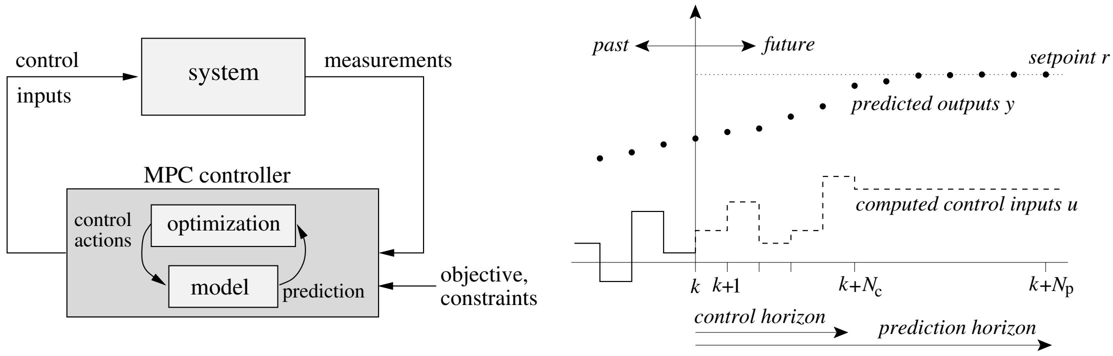

Figure 2: Model predictive control

step forward and repeat the prediction and optimization procedure over the shifted horizons using new system measurements. For more details on MPC scheme we suggest the interested reader to Maciejowski (2002) and Camacho & Bordons (1995).

The main reasons for its wide acceptance are :

- MPC can easily handle constraints on inputs and outputs.
- MPC is flexible to structural changes, changes in system parameters and, unstable processes by its adapting control strategy for every sampling instant.
- MPC is suitable for linear and nonlinear models.

Based on the type of models used in our controller for prediction purposes, MPC can be distinguished as linear MPC and nonlinear MPC (Allgower et al. (1999)). Most of the commercially available MPC uses linear dynamics of the system for prediction and is termed linear MPC. This MPC scheme has a wide literature on its theoretic issues like stability, and robustness (Rawlings (1999)). However, many systems in general exhibit nonlinearity in their behavior. In order to inherit this natural behavior of the system into control theory and to improve the quality of the prediction, nonlinear MPC was introduced. This MPC uses a nonlinear description of the system for prediction.

The aspects which motivate us to use the MPC scheme for our traffic network are as follows:

- Once we have a good and proper model of the traffic system, we can employ the MPC scheme for handling structural changes in a traffic system.
- MPC controller gives considerable importance to the constraints on the traffic and optimizes the criterion function while determining the control actions for the network. The criterion function could be simple and single or a combination of the above mentioned objectives.
- Since MPC offers a strategy which determines the control actions based on the current and predicted future states of the traffic network, we can reduce the adverse effects of the current control actions on the future traffic situation. Unexpected disturbances such as formation of congestion due to the effect of current traffic control actions at some destination can be predicted earlier and handled appropriately by MPC.

- The feedback and receding horizon approach allow to reduce the effects of possible mismatch errors between the actual real-world traffic flows and the predicted traffic flows which in turn enhance the traffic network's behavior.

In this section, we have defined the traffic control problem and discussed about MPC control method and its suitability for traffic networks. In the next section, we will discuss the state-of-the-art in control structures.

3.3 Control structures

3.3.1 Centralized control

In general, a global or centralized control problem can be viewed as a simple level and simple objective method (Singh & Titli (1978)). By simple level, we mean that there is a complete system and a single controller. By simple objective, we mean that the controller computes all the control inputs in a single optimization problem. This framework may also be extended to include systems that have many subsystems and then the control action for each such subsystem depends entirely on the centralized controller.

The structure of centralized control is suitable for small-scale systems and results in global system performance. But when considering large-scale systems such as transport networks, power systems, traffic networks and water distribution, a centralized control structure results in high computational requirements and increasing communication overhead as it has to collect all the inputs distributed across the large system and generate control actions for the whole system. Also it lacks scalability. Furthermore, in case of failures in the system, this structure offers no graceful degradation.

In order to overcome the difficulties in the centralized approach, we can consider decentralized control schemes for controlling large-scale systems.

3.3.2 Decentralized control

In this scheme, the global control is distributed across many independent, loosely coupled subsystems. The local controller computes the control inputs using local measurements and optimizes local dynamics. In this control structure, the decomposition of system leads to simpler controller structures. By using local controllers, the computational burden, data gathering, and storage requirements are much lower. When local controllers do not have any conflicting actions, we can combine the series of local solutions to obtain an overall solution.

However, in practice, independence among the local controllers is unrealistic and thus the resulting global solution will be sub-optimal.

3.3.3 Distributed control

When interactions among the subsystems are strong and each controller is associated with a performance index, then conflicts may arise among the control actions. We can resolve these conflicts among the controllers in a decentralized approach by allowing them to exchange some information about constraints and variables, and to share resources. By doing so, we can bring coordination among the controllers and achieve

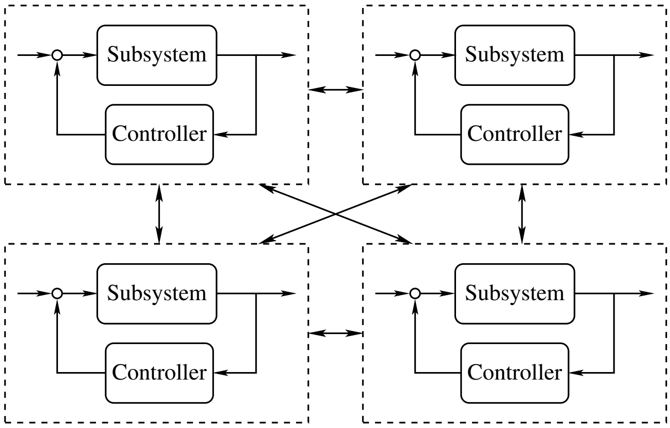

Figure 3: Distributed control strategy

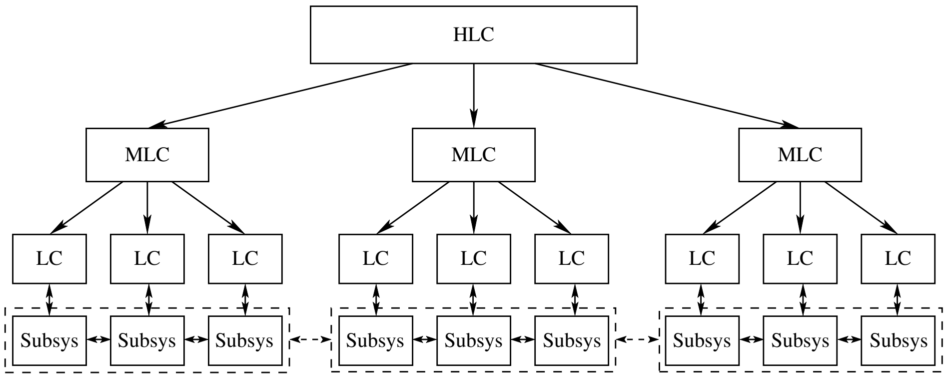

Figure 4: Hierarchical control strategy

better system performance. This type of framework is described as distributed control and is shown in Figure 3. However this approach poses many challenges such as synchronization, coordination and so on.

3.3.4 Hierarchical control

Another way to resolve the conflicts among the controllers is to introduce a second level of control. This second level of control considers the interactions among the subsystems and modifies the objectives and constraints, if required. This approach could be described as multiple levels - multiple objectives. The control is distributed among the multilevel hierarchy of subsystem as shown in Figure 4. The higher level controllers address higher-level, more abstract control problems at slower time scale. The lower level controllers solve more concrete, low-level control problems at fast time scale. This approach decomposes the system structure in such a way, so as to improve the computational efficiency.

3.4 Motivation for distributed and hierarchical MPC in traffic networks

Large-scale systems are systems which can be divided into small-scale, interconnected subsystems. Traffic networks can be considered as large-scale systems. Since the traffic system is large, a global MPC controller may not be sufficient for managing and controlling the system. Its implementation may face the problems of high computational requirement, and huge amount of data collection.

A decentralized MPC for a large-scale system was proposed by Xu et al. (1988), which resulted in bad performance for mutually interconnected subsystems. An alternative approach for handling interconnected subsystem is the distributed control (as seen in Section 3.3.3). It attempts to coordinate control actions among the interconnected subsystems. The distributed MPC controllers (Camponogara et al. (2002)) measure local outputs and determine the actions for local dynamics. This approach requires less data gathering and less computational requirements.

The hierarchical approach decomposes the system into a multilevel hierarchy of subproblems, each level with limited decision and control capabilities, and coordination is required among different levels (as discussed in Section 3.3.4).

In a traffic control context, the higher level controllers (such as roadside controller) will address the coordination control problems among distributed, interconnected subsystems. The lower level controllers (subsystem controller) will receive the commands from the higher level controllers and address the local problems.

So, we propose an approach which possesses the advantages of distributed and hierarchical MPC structure.

4 Control System Framework

In this section, we will describe the most widely used control architecture for an automated highway system. This architecture was proposed and developed at the University of California Partners for Advanced Transit and Highways (PATH) program. This framework assumes that the traffic is organized as "platoons" - closely spaced vehicles and also suggests that by platooning, the capacity on the highway increases (Varaiya (1993)).

4.1 PATH IVHS framework

In the PATH IVHS program (Horowitz & Varaiya (2000); Varaiya (1993); Varaiya & Shladover (1991)), a four-layer control hierarchy was proposed to control the vehicle in an automated highway system. This hierarchy is shown in Figure 5. This framework assumes that a network is made of many interconnected highways. Highways can be again divided into links (about 5 km long). A link is subdivided into section (about 1 km long) and these sections consist of lanes. Now we discuss each layer starting from the top.

- The top layer, called the network layer controller, is responsible for the flow of traffic on the entire highway system. There is only one network layer controller for the whole automated system and it assigns a route to each vehicle that enters the network.

- The second layer is link layer controller, is responsible for smooth traffic flow along a specific highway link, ensuring distribution of traffic flow among lanes.

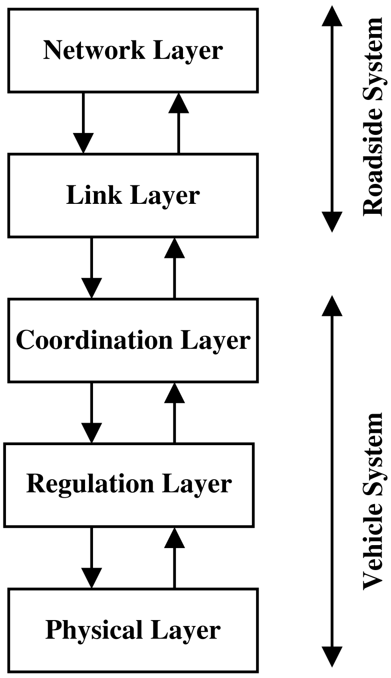

Figure 5: PATH IVHS framework

There is one link layer controller for each highway link. Its primary goal is to assign a path to each vehicle so that it can reach its destination as fast as possible, a target speed for each section, and an optimum platoon size. The control actions issued by this layer are concerned with aggregated information of vehicles rather than individual vehicles or platoons.

- The third layer is the coordination layer. This layer is responsible for selecting the maneuvers (platoon joining, splitting or lane changing) that are required to be carried out in order to realize the assigned path (link layer command). This layer receives the control actions from the link layer and checks if it can start the maneuver, ensuring safety with its neighboring vehicles.

- The next layer in this hierarchy is the regulation layer. There is one such controller for each vehicle. Its task is to execute the maneuvers selected by the coordination layer by issuing control commands to throttle, steering and breaking inputs to the vehicle actuators.

- The last layer is the physical layer. It refers the actual vehicle dynamics. It receives commands from the regulation layer and gives information about its own dynamics (e.g. vehicle speed, acceleration, and engine state) to the regulation layer.

Thus the network and link layer are responsible for the roadside intelligence and each vehicle has its own coordination and regulation layer controllers.

The key point of this design is that it distributes the control and information among the vehicles and coordinates the activities of the vehicles for ensuring safety. This framework is designed to be a trade-off between centralized and autonomy in the control.

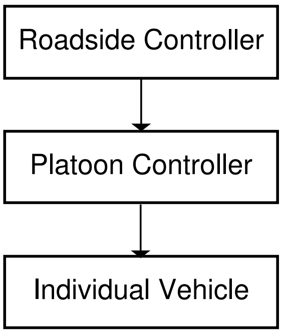

Figure 6: IV based control framework

4.2 Other frameworks

The Japanese Dolphin framework proposed by Tsugawa et al. (2000) and Tsugawa (2000) is also similar to PATH architecture. This framework considers platoon-based driving and their inter-vehicle communication. This framework is vehicle-oriented, which means that it does not require roadside intelligence for their coordination. It mainly uses GPS for vehicle following behavior. They developed WLAN model based on token-ring to communicate each vehicle's dynamics to its neighborhood. In this architecture, a request message has to be send through the network to execute the maneuver and each vehicle in turn has to accept this request and alter their behavior to execute this maneuver.

Another project called CarTALK2000 (Reichard et al. (2002)), is a European project that focuses on driver assistance systems based on inter-vehicle communication. The main objective of this project is to develop a cooperative drive assistance system with self-organizing ad-hoc radio network as communication basis. To achieve a suitable communication system, algorithms for flexible and ad-hoc radio networks with extremely dynamic topologies are developed in this project.

In the next section, we also propose the IV-based control framework which we will use and is highly inspired by the PATH architecture. We are more interested in the roadside/vehicle management. Hence, our project is concerned with interlinking the tasks of link layer and coordination layer controller.

4.3 IV-based control framework

In our project, we propose a framework for control of large-scale traffic networks, which mainly aims at a multi-level control structure with local controllers at the lowest level and one or more higher supervisory control levels and uses a combination and integration of techniques from computer science and control engineering in order to obtain coordination at and across all control levels.

The proposed control framework uses the control measures provided by the IV-based system (as seen Section 2.3) and implements them in a decentralized roadside/vehicle traffic management structure. It is a hierarchical control architecture. The distributed hierarchy is shown in Figure 6.

- The upper layer controller is the **roadside controller**. Each platoon on the highway network appears as a single unit to the roadside controller and therefore can be managed more efficiently. Each platoon is responsible for the control of its individual intelligent vehicle. The roadside controller assigns desired speed for each platoon (ISA), desired safe distance between platoons (Cooperative ACC), metering values on the on-ramps and off-ramps (Ramp metering), desired platoon size, and also provides dynamic route guidance for the platoons. This layer may be permitted to control a part of a highway, entire highway, or a collection of highways.

- The low-level controller is the **platoon controller**. This controller is responsible for control and coordination of each intelligent vehicle in the platoon. The platoon controller receives commands from the roadside controller and coordinates the tasks such as merges or splits within the platoon. Mainly, it is concerned with the intra-platoon activities. A multi-agent architecture may also be implemented for intra-platoon activities.

- At the bottom of the architecture are the **individual vehicles**. They receive commands from the platoon controller and execute them. Here, the vehicle dynamics refers throttle, braking, and steering actions.

4.4 Open issues and solution approaches

Our framework has plenty of opportunities and open problems left to explore. Some of them are listed below:

- First of all, we will implement this multi-level framework for a small-scale system and observe its effects on traffic throughput. As a next step, we will implement this framework for a large-scale traffic network. In this case, on-line optimization of MPC for large-scale traffic network will be a cumbersome task.

- We will also develop efficient control methods and algorithms that will help in achieving cooperation and coordination at and across the hierarchical levels. The performance and complexity of the control methods and algorithms at each levels have to be studied and analyzed.

- We will extend the framework to contain mixed situations in which both IV and non-IV-vehicles are present. Assessment of the performance of the approach has to be carried out.

- We will analyze, verify and investigate the flexibility of the proposed framework for different scenarios of the traffic network. The study can be on investigating what type of traffic models is to be used and how well this framework could be brought into the real traffic picture.

- We will develop corresponding software tools.

- We will analyze the trade-offs between computational complexity and efficiency for this framework.

In order to address these issues and open problems, we propose to use a combination of the following approaches and methods:

- We can organize the collection of roadside controllers in a small-scale and distributed manner. By this solution approach, on-line optimization of small-scale, distributed controllers can be carried to achieve a global objective.
- We can use methods that take the advantages of advanced control techniques and computer science/operations research approaches.
- We can use multi-level modeling with detailed models at lower levels of the control hierarchy and more abstract model at higher level.
- We can use simulation methods and develop protocols and scenarios under which IV and non-IV systems can be mixed in a safe and efficient manner.

5 Conclusions

In this paper, we have discussed some IV technologies with emphasis on applications which help in developing an intelligent road side/vehicle system that takes complete control of the driving tasks by autonomous control systems and also allows for vehicle-vehicle and vehicle-roadside communication to enhance the traffic performance.

Also we have discussed the control problem of a traffic network and focused our attention on MPC control methods. Various control structures are explained. We have discussed the points which motivate us to use distributed and hierarchical MPC control strategy for handling road traffic networks problems.

The PATH IVHS architecture was described and we also propose a control framework which uses IV-based control measures discussed in the earlier sections and implements them in a multi-level control structure for traffic control and management. We conclude the paper with the list of open issues and possible solution approaches. Future work will be to solve one of the open issues by using a combination of solution approaches.

Acknowledgments

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