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# Train Control System for Efficient Track Usage and Reduce Road Traffic

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***Abstract:*** Automatic Train Control (ATC) is the term for a general class of train protection systems for railways that involves some sort of speed control mechanism in response to external inputs. ATC systems continuously monitor all movements of the trains on lines and at stations and provide safe signaling. A large number of automatic functions support the high speeds possible and enabling the line and network resources to be utilized to maximum capacity. ATC use to schedule multiple trains between two stations with small meter gap between adjutant trains. So the railway department can run more train by using the same track without accident problem. Population explosion has resulted in a series of problems, such as traffic jam, environment pollution, and energy crisis. This project focus on channel estimation errors and the tradeoff between MIMO multiplexing gain and diversity gain in making handoff decisions. The handoff problem is formulated as a partially observable Markov decision process (POMDP), and the optimal handoff policy can be derived to minimize the handoff latency.
***Keywords-*** Green computing, railway communication, wireless local area network (LAN), train scheduling

## I. Introduction

A wireless local area network links two or more devices over a short distance using a wireless distribution method, usually providing a connection through an access point for Internet access. The use of spread-spectrum or OFDM technologies may allow users to move around within a local coverage area, and still remain connected to the network. Products using the IEEE 802.11 WLAN standards are marketed under the Wi-Fi brand name [1]. Fixed wireless technology implements point-to-point links between computers or networks at two distant locations, often using dedicated microwave or modulated laser light beams over line of sight paths. It is often used in cities to connect networks in two or more buildings without installing a wired link [2].

A cellular network or mobile network is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver, known as a cell site or base station. In a cellular network, each cell characteristically uses a different set of radio frequencies from all their immediate neighboring cells to avoid any interference [3], [4]. When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission[5].

Intelligent transport systems (ITS) are advanced applications which, without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks[6], [7]. Interest in ITS comes from the problems caused by traffic congestion and a synergy of new information technology for simulation, real-time control, and communications networks. Traffic congestion has been increasing worldwide as a result of increased motorization, urbanization, population growth, and changes in population density [8]. Congestion reduces efficiency of transportation infrastructure and increases travel time, air pollution, and fuel consumption [9], [10].

In the developing world, the migration of people from rural to urbanized habitats has progressed differently. Many areas of the developing world have urbanized without significant motorization and the formation of suburbs. In areas like Santiago, Chile, a high population density is supported by a multimodal system of walking, bicycle transportation, motorcycles, buses, and trains. A small portion of the population can afford automobiles, but the automobiles greatly increase the congestion in these multimodal transportation systems. They also produce a considerable amount of air pollution, pose a significant safety risk, and exacerbate feelings of inequities in the society [11].

Intelligent transport systems vary in technologies applied, from basic management systems such as car navigation; traffic signal control systems; container management systems; variable message signs; automatic number plate recognition or speed cameras to monitor applications, such as security CCTV systems; and to more advanced applications that integrate live data and feedback from a number of other sources, such as parking guidance and information systems; weather information; bridge deicing systems; and the like.

Additionally, predictive techniques are being developed to allow advanced modeling and comparison with historical baseline data. Some of these technologies are described in the following sections.

Various forms of wireless communications technologies have been proposed for intelligent transportation systems. Radio modem communication on UHF and VHF frequencies are widely used for short and long range communication within ITS. Short-range communications (less than 500 yards) can be accomplished using IEEE 802.11 protocols, specifically WAVE or the Dedicated Short Range Communications standard being promoted by the Intelligent Transportation Society of America and the United States Department of Transportation. Theoretically, the range of these protocols can be extended using Mobile ad-hoc networks or Mesh networking. Longer range communications have been proposed using infrastructure networks such as WiMAX (IEEE 802.16), Global System for Mobile Communications (GSM), or 3G. Long-range communications using these methods are well established, but, unlike the short-range protocols, these methods require extensive and very expensive infrastructure deployment [12]. There is lack of consensus as to what business model should support this infrastructure. Auto Insurance companies have utilized ad-hoc solutions to support eCall and behavioral tracking functionalities in the form of Telematics 2.0.

### *A. Objective*

The main objective of this project is to reduce the handoff decision taking time by using partially observable Markov decision process (POMDP) .A handoff scheme in ATC systems based on WLANs with multiple-input–multiple-output (MIMO) technologies to improve the handoff latency performance [16]. In particular, the channel estimation errors and the tradeoff between MIMO multiplexing gain and diversity gain in making handoff decisions.

### *B. Train Control System*

In today’s railway industry, there are many different types of train control systems. The principal intent of a train control system is to prevent collisions when trains are traveling on the same track, either in the same direction (trains following one another) or in the opposite direction (two trains moving toward each other). These systems also permit safe movement of trains as they cross from one track to another.

Early train control systems were very simplistic in architecture. As train technology and operation evolved over time, these control systems grew to have more and more complex architectures. The latest architecture is known as Automatic Train Control (ATC) system. As will be discussed, ATC uses bidirectional radio frequency (RF) data communication between the trains and control locations distributed along the tracks (wayside).The use of a track circuit to determine the location of a train is called wayside centric. Wayside centric means that there are devices located near the rails that are employed to detect the presence of trains [13].

As stated earlier, another function of a train control system is to ensure safe movement of a train from one track to another. The term interlocking was coined in the early days of train control systems with the Saxby-Farmer mechanical interlocking machine. This device mechanically interlocked the movement of switch machines and wayside signals, e.g., signals must be made to stop before a switch machine can be moved, and signals could not be cleared until the switch machines are locked in the proper position. With the invention of track circuit, train location was integrated into the Saxby-Farmer interlocking machine.

As time progressed, these purely mechanical devices were replaced with electromechanical devices and then all-relay devices. Today, computers are frequently used to implement the safety functions of interlocking. Independent of the signaling architecture (e.g., ATC or FB), an interlocking must provide certain vital functions, which include approach locking, route locking, detector locking, direction (traffic) locking, etc. These functions ensure that switches cannot be moved under a train and head-on collisions do not occur [14]. The goal of an ATC system is the same as the traditional system, e.g., safe train separation; however, it has also the challenge of minimizing the amount of wayside and trackside equipment. This means elimination of traditional train-detection devices, i.e., track circuits. With the elimination of track circuits, ATC systems’ communication between the train and wayside must be accomplished by other means than a track circuit.

### *C. System architecture*

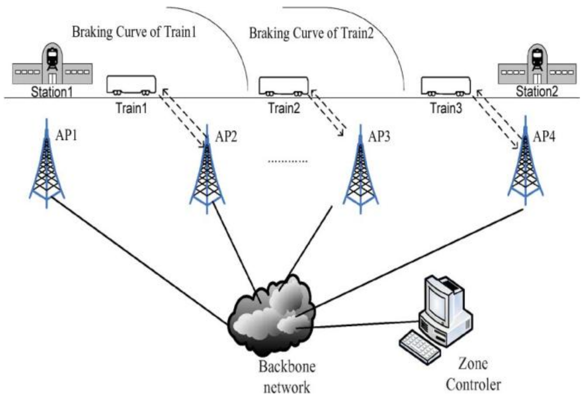


Fig: 1 ATC System Design

Today's ATC systems are vehicle centric systems, where the method of determining the location of the ATC train is to have the ATC train (or vehicle) itself; determine its location, direction, and speed; and report this information to wayside equipment. Some of the devices that are employed by a vehicle to determine its location on the rails include tachometers, accelerometers, gyroscopes, global positioning system (GPS), transponders (or tags), radar, lasers, loop transpositions and digital track maps. Different manufacturers of train-control systems employ different combinations of these devices for train location. In general, the train has to initialize its location (using tags and/or GPS) on the rails and remember its location and direction as it traverses the line (using track map, tachometer, radar, laser, and loop transposition, accelerometer, and/or gyroscope info).

In an ATC system (vehicle centric), each ATC train's position is communicated to a computer called a zone controller. The ATC system ensures that the functions of approach, route, traffic, and switch locking are implemented [16]. ATC systems can implement the interlocking functions in two ways: the first is by having separate devices, i.e., one device for the interlocking function (interlocking controller) and another for ATC safe train separation (zone controller). The second is to have the interlocking function to be designed into the zone controller. The majority of ATC systems follow the first method, i.e., using a separate interlocking controller and zone controller.

With the zone controller interfaced to the interlocking controller when required, the zone controller can override specific functions of the interlocking controller. For example, the interlocking controller will not permit two trains in one axle counter block. However, for ATC trains, having two trains in one axle counter block is safe as long as these trains are separated by SBD. In such a case, the zone controller overrides the interlocking controller, permitting two ATC trains to be in the same axle counter block. The majority of ATC systems require each train to communicate its location to a zone controller. This train location information is conveyed to the zone controller via a data communication system (DCS) using both wireless and wired Ethernet. Through these communications, the zone controller knows the location of all ATC trains within its control area. There are three control methods employed by the various system suppliers to keep the ATC trains safely separated.

The first method has the zone controller transmitting specific information to all ATC trains (simulcast transmission) in its control area. This information includes the location of all trains in the control area, all switch positions, all signal aspects, etc. Each ATC train then calculates its safe movement limit and speed profile using this information. The second method has the zone controller communicating to each ATC train its specific speed requirement. The onboard equipment then follows this speed requirement by controlling the propulsion/braking of the train. This technique reduces the computing requirements for the vehicle's onboard equipment. In the third method (which is the most commonly used today), the zone controller carries on or conducts individual RF dialogs with each ATC train and issues a movement authority to each train based on where other trains are in the zone controller's area, as well as switch positions, station stops, etc. A movement authority includes a physical track point or limit, which the train's front end cannot proceed beyond.

## II. Design Goal

### *A. Train Ground Communication*

In this system, continuous bidirectional wireless communication between each SA on the train and the wayside AP is adopted, instead of the traditional fixed-block track circuit. The railway line is usually divided into physical areas. Each area is under the control of a zone controller (ZC) and has its own wireless transmission system. The identity, location, direction, and speed of each train are transmitted to the ZC. The wireless link between each train and the ZC must be continuous to ensure that the ZC knows the location of all the trains in each area at all times. The ZC transmits to each train the location of the train in front of it, and a braking curve is given to enable the train to stop before it reaches that train. Theoretically, two successive trains can travel together as close as a few meters in between them, as long as they are traveling at the same speed and have the same braking capability.

Train–ground communication systems are primarily designed to connect each component of ATC systems: ZCs, APs along railways, and train aboard equipment. A basic configuration of a WLAN-based train–ground communication system. Following the philosophy of open standards and interoperability, the backbone network of the train–ground communication system includes Ethernet switches and fiber-optic cabling that is based on the IEEE 802.3 standard. The wireless portions of the train–ground communication system, which consist of APs along the railway and SAs on the train, are based on the IEEE 802.11 series standard. When a train moves between successive APs, the received SNR rapidly changes. The communication latency will be a serious problem when the SA is in deep fading. Furthermore, when a train moves away from the coverage of an AP and enters the coverage of another AP along the railway, the handoff procedure may result in long latency. To minimize the latency, we present a train–ground communication system based on MIMO-enabled WLANs to improve the handoff performance.

### *B. Channel State Estimation*

The ATC train–ground communication system based on MIMO-enable WLANs. The application-layer data packets being encapsulated in the User Datagram Protocol are then transferred between trains and wayside equipment using Internet Protocol and WLANs with IEEE 802.11 MAC and MIMO-enabled physical layer. A critical issue in the aforementioned system is the handoff decision policy (i.e., when to perform a handoff) and the corresponding physical-layer parameter adaptation policy (i.e., the tradeoff between MIMO diversity gain and multiplexing gain).

In high-speed environments, wireless channels are dynamically changing. If these policies are not carefully designed, long communication latency may occur, which will significantly affect the performance of ATC systems. Therefore, an efficient handoff decision policy and a physical-layer parameter adaptation policy are needed to decide at which time to trigger handoff and what physical-layer parameters should be used, which will be studied in the succeeding sections.

### *C. Minimize Communication latency*

The diversity gain and spatial multiplexing gain can be realized with a MIMO system, and there is a fundamental tradeoff between them. For each spatial multiplexing gain r, the best diversity gain $g*(r)$ is the supermom of the diversity gain achieved over all schemes. With long-enough block lengths, the optimal multiplexing–diversity tradeoff $g*(r)$ is given by the piecewise-linear function connecting the points $(r, g*(r))$ for $r = 0, 1 . . . , \min (QA, QS)$

$$g*(r)=(QA-r)(QS-r) \qquad (1)$$

Where MA and MS are the number of transmit and receive antennas, respectively; and they map to the number of wayside AP and train SA antennas in our proposed system. We assume that the aforementioned optimal tradeoff performance can be achieved with a family of carefully designed codes in our study.

To turn the piecewise linear tradeoff curve into a differentiable curve, we approximate (1) with a differentiable function as

$$g(r) = (QA - r) (QS - r), 0<=r<= \min (QA, QS) \quad (2)$$

This differentiable approximation is a lower bound of (1), which gives a subset of the feasible diversity–multiplexing tradeoff region. Although this can potentially lead to a suboptimal solution of the problem due to the reduced tradeoff region, this approximation is close to the exact tradeoff relationship, and the reduction of the feasible tradeoff region is small. Thus, the impact on the results should not be significant.

## III. Network Configuration

Markov decision process (MDP) provides a mathematical framework for modeling decision making in situations where outcomes are partly random and partly under the control of a decision maker. In our proposed ATC train–ground communication system, the SA on the train makes handoff decisions at specific time instances according to the current state s(t), and the system moves into a new state based on the current state s(t), as well as the chosen decision a(t). Given s(t) and a(t), the next state is conditionally independent of all previous states and actions. This Markov property of state transition process makes it possible to model the optimization problem as an MDP. Furthermore, in ATC systems, due to channel sensing and channel state information errors, the system state cannot be directly observed. As a result, we formulate the optimization problem as a POMDP, in which it is assumed that the system dynamics are determined by an MDP. However, the underlying state can only be observed inaccurately or with some probabilities.

A POMDP can be defined by a hex-tuple $(S, A, P,\Theta,B,R)$.S stands for a finite set of states with state i denoted by si. A stands for a finite set of actions with action i denoted by ai. P stands for transition probabilities for each action in each state, and q denotes the probability that system moves from state si to state sj when action a is performed. $\Theta$ stands for a finite set of observations, and $\theta$i denotes the observation of state i. B is the observation model, and ba j$\theta$ denotes the probability that $\theta$ was observed when the system state is sj and last action taken is a. R stands for the immediate reward. ra ij denotes the immediate reward received for performing action a, and the system state moves from si to state sj , with an observation θ.

## IV. Schedule Multiple Trains

In ATC train–ground communication system, the SA on the train first has to decide whether the connection should use the current chosen AP or connect to the next AP. (We assume that the SA on the train will not be in the coverage of three successive APs.) Second, the multiplexing gain in the physical layer should be decided. We assign every AP along the railway with a distinct number. Let C be the AP that covers the SA; then, the other one is C + 1. The current composite action ca(t) ∈ A is denoted by

ca(t)={ha(t),ma(t)} (3)

Where ha(t) is the handoff action, and ma(t) is the multiplexing gain action (0 < ha(t) < min(QA,QS)). ma(t) = S + 1means handoff to the next AP; ha(t) = S means stay in the old AP. Based on the handoff decision making , the train will control by ZC and send the breaking curvature to the train which are very close.

## V. Evaluation

We first compare the POMDP policy performance in our proposed MIMO-enabled ATC system with the performance in traditional ATC systems without MIMO technology. In MIMO-disabled ATC systems, the SA on the train makes handoff decisions according to the POMDP policy without MIMO parameter adaptation. We also compare the performance of our optimal POMDP policy with three other heuristic policies. For the first heuristic policy, the train SA makes handoff decisions according to the POMDP policy, but the MIMO multiplexing gain is fixed. That is, the physical-layer parameter is not dynamically adapted. This policy is denoted as the static policy. For the second heuristic policy, we adapt physical-layer multiplexing gain according to the channel state, but we make handoff decisions only based on the immediate reward and not on the long term reward. We denote this policy as greedy policy. For the third heuristic policy, channel estimation errors are not considered in making handoff and physical-layer parameter adaptation decisions. In other words, the channel is assumed to be perfectly known by the SA, but estimation errors occur in the simulations. We denote this policy as the no-estimation-error policy.

Fig.2 shows the average handoff latency under the proposed POMDP policy in our proposed MIMO-enabled ATC system and traditional systems without MIMO technology. The handoff latency under the static policy with different multiplexing gains is presented as well. As we can observe in the figure, the communication latency in our proposed MIMO-enabled ATC system is always better than the system without MIMO technology. This is because the MIMO diversity gain decreases the packet loss probability during the handoff procedure, and the MIMO multiplexing gain decreases the time needed to transmit a packet. The decreased packet loss probability and packet transmission time both contribute to the communication latency performance improvement. In addition, our optimal POMDP policy always gives the best average handoff latency compared with the static policy. This is because channel state rapidly changes in ATC systems, and we need to dynamically adapt the physical-layer parameters according to the channel state to achieve the optimal performance.

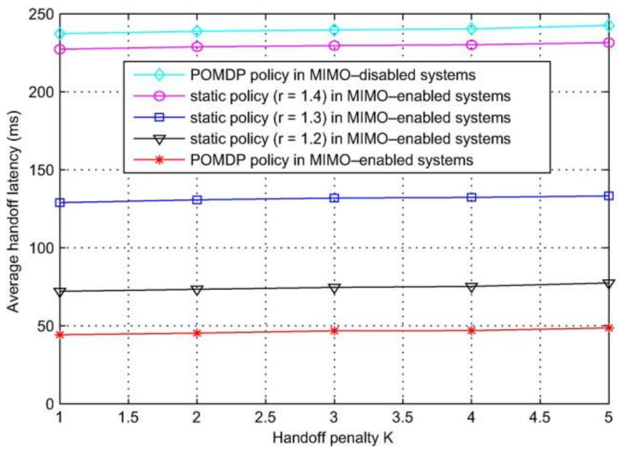


Fig: 2 Performance improvements of Hand-off.

## VI. Conclusion

ATC systems have stringent requirements for wireless communication latency. The dynamic radio propagation environment and frequent handoffs can cause significant communication latency in WLAN-based ATC. In this paper, ATC train–ground communication system based on MIMO-enabled WLANs and considered wireless channel estimation errors and MIMO working mode to improve the handoff latency performance. Based on the inaccurate channel state information, handoff decisions have been made, and physical-layer MIMO parameters have been adapted to minimize the communication latency. The problem has been modeled as a POMDP. Simulation results have been presented to show that the proposed POMDP-based policy can significantly decrease the average handoff latency in ATC systems. The future work of this project is to implement the method in real ATC systems to evaluate the performance and provide more security to bidirectional transport system for high speed trains.

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