

# Virtual Track: Applications and Challenges of the RFID System on Roads

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## Abstract

The RFID System on Roads (RSR), which includes RFID tags deployed on roads and RFID readers installed on vehicles, is an essential platform for future transportation systems. It can provide unique features that are missing from the current systems, including lane level position, road traffic control information, vehicle distance estimation, real time driving behavior analysis, and so on. Based on these features, several novel vehicular applications can be implemented, which can significantly improve the transportation safety and efficiency. Specifically, the proposed applications on RSR include Assisted Navigation Systems, Electrical Traffic Control, Unmanned Patrol Systems, Vehicle Distance Estimation, Parking Assistant System, Route Tracing and Access Control, Unmanned Ground Vehicles. We also investigate the corresponding engineering/system and research challenges for implementing RSR and its applications in this article.



On November 18, 2003, the “Zero Fatality, Zero Delay” safety philosophy was proposed at the World Congress on ITS (Intelligent Transportation Systems and Services) in Madrid, Spain. This exciting vision represents a new concept of the way ITS should be designed and deployed. “Zero Fatality, Zero Delay” means that “in the future people and goods are transported without delay, injury, or fatality by integrated systems that are built and operated to be safe, cost effective, efficient, and secure.” Nevertheless, 10 years have been passed but no one knows how long we still need to go to reach this goal — the fatality in recent years is still unbearable.

According to the vehicle traffic fatal crash report [1] of FARS (Fatality Analysis Reporting System), 30, 196 and 30, 862 people were killed in police-reported motor vehicle crashes across the states in 2010 and 2009, respectively. Analysis by BTS (Bureau of Transportation Statistics) [2] on the 2004-2008 accident level data showed that the main factors in fatal vehicle crashes include traffic control, vehicle speed, road type, and road characteristics, among which the functionality of traffic control carries the most weight. In 2009, 48.6% fatal crashes occurred at roads with a speed limit of 55mph or higher, 40.9% on off roadways or shoulders, 47.0% in dark environments, 30.9% involved vehicles that did not go straight, and 667 people were killed in construction or maintenance zones.

These shocking numbers force us to think about the following questions: What are missing from the current transportation system? What can be done to enhance the roadway safety with emerging technologies? Can we design an *integrated system that is safe, cost effective, efficient, and secure*? In this article, we discuss the RFID System on Roads (RSR) to address these issues. RSR is a platform that can provide accurate and timely road information in future transportation systems. Drivers can obtain

necessary information such as position, speed limit, surface condition, and exit information from RSR to improve their awareness of the driving circumstances. RSR is also a traffic-related information collector: it can collect vehicles’ actions such that the driving behaviors can be analyzed, based on which road supervisors can regulate the corresponding drivers. Moreover, RSR is a driving command issuer: it can direct unmanned vehicles to take appropriate actions at specific locations.

In the rest of the article we first introduce the RSR platform. A number of possible applications that could be established on RSR are then proposed and discussed. Finally, the engineering/system and research challenges are elaborated in detail for RSR and its applications.

## The RFID System on Roads

The RFID System on Roads (RSR) is designed to support future intelligent vehicular applications. It consists of RFID tags [3], RFID readers, Information Processing Units (IPU), and Information Sharing Units (ISU). RFID tags are deployed on road surfaces, and RFID readers are installed at vehicles. Vehicles obtain information from embedded sensors and RFID tags, which will be processed by IPU and then broadcast to other vehicles and base stations via V2V/V2I (Vehicle to Vehicle/Vehicle to Infrastructure) communications employing DSRC (Dedicated Short-Range Communication [4]). Figure 1 presents an illustration of the RSR, in which RFID tags with triangle read areas are deployed in the center of each lane, RFID readers are installed at the front or the rear of the vehicles, and vehicles are equipped with devices (e.g. DSRC) to communicate with each other and the roadside base stations. In Fig. 1, the green stars are RFID tags with regular road information (e.g. position) while a red star represents a RFID tag containing exceptional (irregular) information (e.g. distance to a hole on the road) that needs to be shared with approaching vehicles. For example, vehicle *a* reads a red tag,

<sup>1</sup> The data is obtained from <http://www.fars.nhtsa.dot.gov/Main/index.aspx>.

and sends the tag's information to vehicle *b*. Vehicle *b* shares this information with vehicle *d* and reports it to the base station. Then the base station advises each vehicle (e.g. vehicle *c*) approaching to the area with the information.

In RSR, a tag may store information such as its position, the current direction of the lane it resides, the local traffic information, traffic sign information, speed limit, etc. Such information is programmed into the tag by road supervisors with their authorized keys. Vehicles could obtain these information through reading the tags when passing-by. A typical data flow in RSR and the RSR layered architecture on vehicles are illustrated in Fig. 2 and Fig. 3, respectively. In RSR, a vehicle can obtain near real-time road information via two methods: reading RFID tags and receiving data from nearby vehicles and base stations. Each vehicle is equipped with three RSR components: a RFID reader, IPU, and ISU. After successfully reading a tag or receiving a data packet via DSRC devices, the vehicle sends the obtained information to IPU. Based on application-specific requirements, IPU processes the information and delivers the results to relevant RSR applications. Emergency information may be forwarded to ISU directly such that they can be sent to other vehicles as soon as possible. Applications may also send data to ISU for the purpose of information sharing. ISU packages the data it receives according to the category and priority of the data, and then sends them to other vehicles or base stations. Each base station reports road conditions to the traffic center, which also advises the base station with the nearby road conditions.

Currently, the cost of a RFID tag is less than 1 U.S. dollar, and it is for sure that emerging technologies will make the tags cheaper and smarter. As a result, we can foresee that deploying RFID tags in large-scale on roads is possible and practical, and RSR can be gradually upgraded to support more intelligent vehicular applications such as autonomous vehicles.

## Applications of RSR

In this section, a number of application scenarios based on RSR are elaborated. They are designed to address the problems mentioned earlier. A brief summary that compares the cons and pros of the RSR applications with existing technologies is outlined at the end of this section.

### RSR Assisted Navigation Systems

In RSR Assisted Navigation Systems (RSR-ANS), RFID tags are aware of their own locations, and a vehicle estimates its position by acquiring the tag's position when passing-by. As RSR-ANS is a ground system, tags should provide more abundant information. Typically, the information that are valuable to drivers include: Traffic Direction, Speed Limit, Lane Regulation, Lane Number, Lane Destination, Lane Shape, Lane Condition, Lane Statistics, and Event Notification.

With these information, RSR-ANS users can enjoy the real time and lane level navigation services, which are impossible with the current Global Positioning System (GPS) that usually provides a low positioning accuracy. Moreover, today's GPS based navigation systems often do not function well at cities with tall buildings such as downtown Chicago. Even worse, they may output wrong directions when the GPS signals appear occasionally or when the digital map is obsolete. As the performance of RSR-ANS cannot be affected by the surrounding environments, RSR-ANS could be a better choice

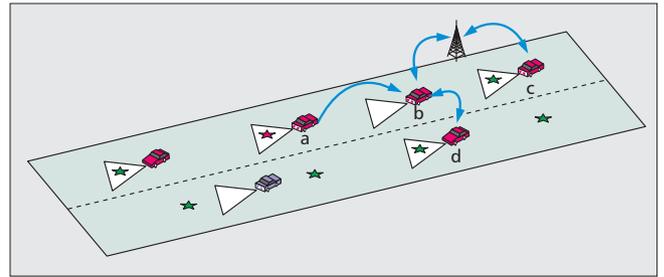


Figure 1. An illustration of the RSR.

for city navigation. Furthermore, it works in tunnels or at cloverleaf intersections where GPS navigation could easily fail. In addition, with abundant lane-level information, RSRANS can provide drivers with situation-awareness such that proactive actions can be readily taken for safety enhancements. A few earlier works toward building RSR-ANS have been reported in [5–7]. Chon et al. [5] proposed the idea of using stationary RFID tags deployed on roads to localize vehicles when passing-by. Lee et al. [6] investigated the relationship between the tag read latency and the vehicle's speed, and evaluates the feasibility and practicality of applying commercial RFID tags and readers to the vehicular environment on a test road. In our prior research [7], we considered issues such as tag deployment and read scheduling for the design of RSR-ANS.

### RSR Assisted Electrical Traffic Control

According to the BTS's report, malfunctioning traffic control is the major reason for fatal crashes. There are many reasons that can negatively affect the traffic control, such as Failed Traffic Lights, Non-Line-of-Sight (NLOS) Traffic Signs, MissLeading Traffic Signs. To overcome the problems caused by malfunctioning traffic controls, RSR Assisted Electrical Traffic Control (RSR-ETC) can be implemented to provide correct and near real-time traffic control information for drivers. By reading the stored traffic control information from a RFID tag when passing-by, a vehicle should not suffer from the NLOS traffic sign problem. To provide near real-time information in RSR-ETC, RFID tags are required to be reprogrammable such that authorized vehicles or persons can

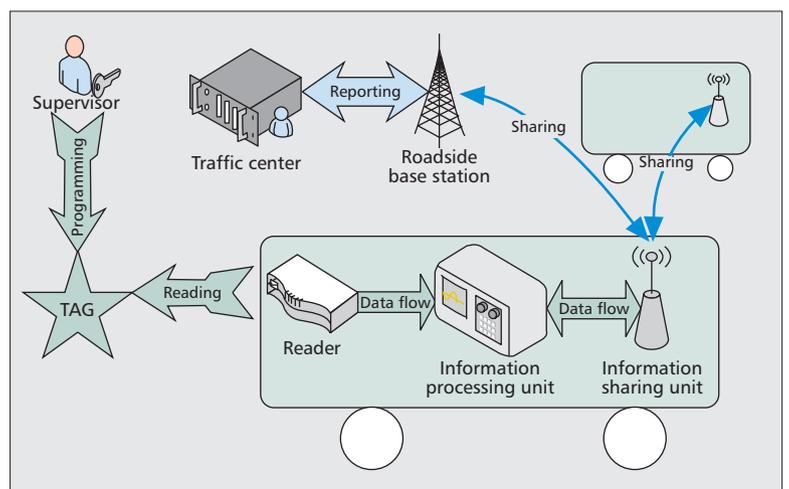


Figure 2. The RSR data flow, where the tan arrows represent RFID communications (the reader reads the tag, and the supervisor writes the tag), the green arrows represent inter-vehicle data transmissions (the reader sends tag data to IPU, and the IPU sends the processed information to ISU), the navy arrows represent DSRC communications (information shared among vehicles and base stations), and the sky blue arrow represents the Internet communications (base stations send the information to the traffic center).

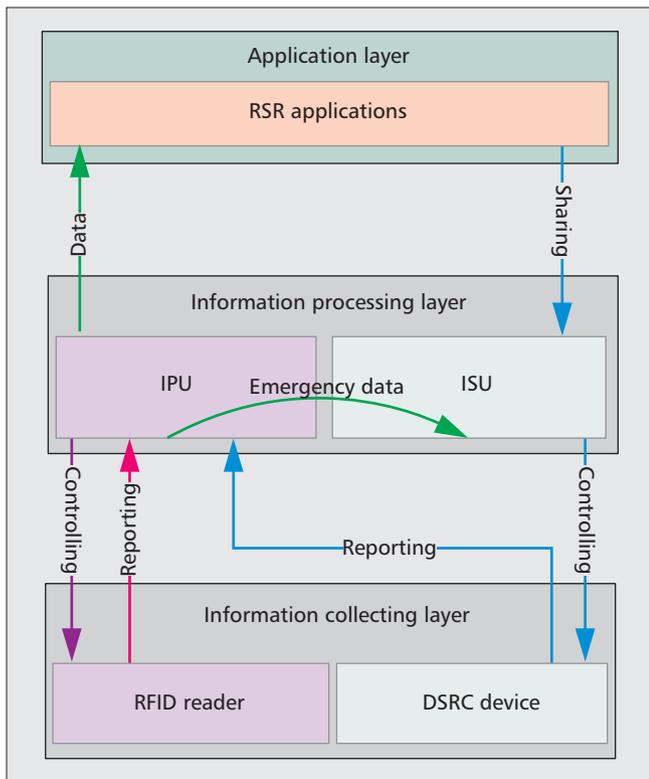


Figure 3. The RSR layered architecture on vehicles.

easily update the tag information whenever needed. Thus when problems such as failure of traffic lights are detected, the reprogrammed RFID tags can inform the approaching drivers of the situation such that they can drive through with caution. The only similar research under our awareness is the Road Beacon System [8] that addresses the NLOS traffic sign problem, but unfortunately no technical detail is disclosed.

#### RSR Based Unmanned Patrol Systems

Intuitively the accident rate should be low if all vehicles are operated by drivers who are well-mannered according to traffic rules. However, even the most well-behaved drivers might have the experience of being stopped by patrols on roads for some violations that might be caused by unexpected reasons such as driving in a unfamiliar environment or temporally forgetting rules. Moreover, many drivers are inclined to committing certain types of violations that frequently occur but are mostly undocumented as patrols are not present everywhere. For the first case, RSR-ANS and RSR-ETC can assist the drivers to improve their awareness of road conditions and remind them of the corresponding traffic rules. To reduce the second type of violations, patrols should be everywhere such that all violations are cited without exceptions. Definitely the current traffic cameras and patrol systems could not provide that level of surveillance. Thus a  $7 \times 24$  monitoring system, named RSR based Unmanned Patrol System (RSR-UPS), can be implemented to strengthen the current traffic regulations.

In RSR-UPS, a RFID reader installed on a vehicle sends collected information to a device called On-Board Patrol (OBP), which is installed and operated only by authorities such as police officers. OBP judges whether a driver has violated the rules based on the information it has received. It can detect the violation such as *Speeding, Turning Violations, Failing to Stop/Yield, Passing Violations*, etc. If the OBP detects a violation, it should advise the driver and/or report to the police department via either the V2I/V2V network or upload at specific locations such as an inspection station.

#### Vehicle Distance Estimation on RSR

The distance between two vehicles is one of the most critical parameters for safe driving. With the awareness of the realtime distance to the vehicle in front, a driver can take proper actions (like breaking) such that a safe distance can be maintained. People usually estimate the distance by vision and their experiences. As a result, the corresponding accuracy is significantly affected by the visibility. To measure the distance in an unclear environment such as at night or under a severe weather condition such as a storm or a heavy fog, distance radars can be employed as reported in the Pre-Collision System [9]. However, radars measure the “line distance”, not the “road distance”, which is more appropriate as vehicles do not always travel in straight lines. For example, in U/Z shaped or curved roads, the road distance records the distance to be traveled along the lane between the two vehicles. Motivated by these observations, we design the RSR based Vehicle Distance Estimation (RSR-VDE) system to provide road distance information. In RSR-VDE, a vehicle can derive the time difference of passing a tag between itself and the vehicle in-front by reading the same tag. Accordingly, the success of RSR-VDE depends on the time synchronization among the vehicles and the fast-speed RFID read and write operations as the time information of a vehicle should be meaningful to the one behind. After obtaining the information from several consecutive tags, a vehicle can estimate the road distance to and the speed of the vehicle in-front, which should provide more accurate information for safe driving.

#### Parking Assistant Systems on RSR

Usually it is extremely hard to find a parking spot in big cities. Even worse, an open space, where a driver might have spent a lot of time to locate, may not be available for parking due to policy issues, which can be very complicated to follow, and might be changed temporally because of events or street works such as tree cutting. As a result, parking could be a headache and is frustrating even for a local driver. The situation becomes even worse when a parking ticket is issued or a vehicle is tolled because the driver does not notice the policy in the parking sign and leaves the car with confidence.

To tackle these challenges, we propose to design a RSR based Parking Assistant System (RSR-PAS) to provide realtime and accurate parking policies to drivers. In RSR-PAS, a vehicle obtains the rules through reading RFID tags in the parking spot. Combining with the local time, RSR-PAS can advise the driver with information such as how long he can park and how much the parking costs. When cooperating with V2I systems, RSR-PAS can also be used to pay the parking fee automatically. To enforce the parking policy, RSR-PAS can be employed to detect parking violations. For instance, by reading the tags in every given interval, RSR-PAS can estimate how long the vehicle has been parked on the spot. If the parking time is more than that is specified by the rule (such as 2 hours), RSR-PAS could report a violation through V2I communications.

#### Route Tracing and Access Control on RSR

The RSR based Route Tracing and Access Control (RSR-TRAC) system is designed to track the route of a vehicle and to help authorities to control the vehicle’s accessibility to a protected area. In RSR-TRAC, tags provide the road access requirements (such as priority and keys) as well as their positions, and vehicles record their routes. With such a system, it is easy for a driver to figure out whether the vehicle has the right to drive along the road by checking the road access requirements. If a vehicle appears on a road where it is not authorized to access, RSR-TRAC should record the violation and report to authorities through the V2I network.

In RSR-TRAC, vehicles can also obtain secret keys by reading the tags. A secret key could be a cipher for a gate,

which should be changed periodically. To access a protected area, RSR-TRAC requires that vehicles possess all the required keys in a specific order. With such an access control policy, RSR-TRAC could be able to guarantee that

- 1 The vehicle has passed all the required security gates in order
- 2 The vehicle is the one that has passed all the gates and has not been compromised (through checking the time since passing the first gate and changing keys timely)
- 3 The vehicle does not access any unsecured area (through checking the route)
- 4 The vehicle only access its allowed areas (through checking the route)

Moreover, by analyzing the routes of a vehicle, the integrity of a security system could be improved. For example, if two consecutive readings are obtained from two tags that are not supposed to be reachable continually, there might exist unexplored paths or tag failures in the system.

### *Extension to Pedestrian Applications*

Note that by extending the idea of RSR to indoor environments and private driveways, new applications can be built for emerging requirements. An example is pedestrian navigation, for which RFID tags are deployed on indoor or outdoor walkways, and people carry RFID readers. The applicability of pedestrian RFID positioning in indoor environments has been validated in [10]. In such type of applications, RFIDs are planned to be used for indoor navigation such as locating a particular store in a shopping mall. Another example is office access control. With the route and the secret keys a user possesses, the security level of an office in a big building, where there exist multi-paths to everywhere, can be significantly strengthened.

### *RSR Tracks for Unmanned Ground Vehicles*

Autonomous vehicles have become a dream of many people in decades. Governments, universities, and private companies have made great efforts on this research topic such as Boss [11], Google's driverless car [12], General Motors [13], and Vislab's autonomous car [14]. For sure, it is still far from having unmanned vehicles everywhere on roads because of the feasibility of the technology and the economic reasons. Optimistically saying, manned vehicles, half-unmanned vehicles, and driverless vehicles will be seen on the same roads for a long time. Then, will drivers, we human beings, feel comfortable to share a lane with unmanned vehicles? Not conservatively, the answer will be NO for most of us for now. Thus, one might require that driverless vehicles only run on specific lanes/roads, which restricts unmanned vehicles on tracks. However, it is unwise to build physical tracks for driverless vehicles on roads. One reason is that the cost will be high; the other is that the scalability and the adaptability are low. Moreover, by dividing the current roads into physically isolated lanes, the efficiency and the utilization of roads could be decreased. Therefore, a flexible system that can provide accurate (both temporal and spatial) road information will be an essential infrastructure for autonomous vehicles.

Since unmanned lane information can be stored in RFID tags, RSR could be an excellent candidate system to support driverless vehicles for the following reasons.

- RSR is a less expensive system to provide similar functions as those of the physical tracks.
- RSR is scalable. Both deployment and redeployment are easy.
- RSR is flexible and tags are reprogramming. Therefore the unmanned lane information can be updated on demands.
- Human drivers can use an unmanned lane if they feel it is safe.

- RSR provides a set of systems to assist both manned and unmanned driving, such as navigation, traffic sign, parking, access control, and distance estimation.
- RSR can provide information to assist patrols. For example, a vehicle's trace route with time stamps can help to identify who had committed the fault that caused an incident between an unmanned vehicle and a humanoperated vehicle, which could be a future problem.
- RSR is robust. As RFID tags are cheap, it is possible to make a relatively dense deployment. As a result, a single tag's failure will not affect the system, and such a failure can be easily detected.

Additionally, the first attempt for employing RSR to assist autonomous vehicles could emerge where the vehicles have fixed routes such as campus buses. Besides the unmanned lane information, RFID tags can also store detailed instructions such as a right turn instruction to command specific vehicles on the routes.

### *Summary for Applications On RSR*

RSR is a platform for vehicular related applications. Applications of RSR have several unique features that can not be achieved by the existing systems or technologies. Table 1 briefly summarizes the applications proposed in this section and compares them with the existing works.

Applications on RSR significantly improve the current transportation system in terms of security, reliability, availability, scalability, realtime, accuracy and efficiency. To our knowledge, RSR is the only system that can provide extensive essential support for transportation. It can be concluded that RSR does have the potential to play a key role in future transportation systems.

Although RSR-based applications have attractable features, undoubtedly there exist many research and engineering challenges to be overcome before it can be realized in the real world. The challenges include the issues from the low-level hardware (such as antennas) designs to the high-level software (such as user interfaces) developments, from protocol (such as tag localization) implementations to large-scale network management (such as topology control), from intrasystem communications (such as tag readings) to intersystem collaborations (such as coordinating with GPS and V2V/V2I communication systems).

### *Challenges for RSR and Its Applications*

The existing RFID products and technologies motivate the design of RSR and its applications. But certainly they are not ready for the new RFID applications mentioned above as RSR brings in new requirements and design elements from the area of vehicle networks.

### *Engineering/System Challenges for RSR*

Unlike the conventional RFID products, RSR requires the tags and readers to have the following unique features:

- The relation between readers and tags should be close to one-to-one in RSR [7] such that reading ambiguities can be avoided. The one-to-one relation should be guaranteed by jointly considering the communication ranges (power control) of the readers and tags, the antenna design (directional antenna), and the deployment strategies of the tags.
- Applications on RSR require a tag to have a large capacity in order to store more information than just its ID. For example, the lane and traffic rules for navigation generally require more storage space.
- Based on the US highway standard and the calculations in [7], a tag's maximum communication range is 2.68m, and the maximum contact time is 0.06s for a vehicle at 160kmh.

Applications	Comparing	Pros	Cons
Navigation	GPS	Lane Level Up To Date Map Metro Area More Information	Specific Area
Traffic-Control	Sign Light	No Misleading No Blocking	
Patrol	Human Camera Radar	7 × 24 Available Bigger Coverage	Not Comprehensive
Distance-Measuring	Radar	Long Range Curved Roads	Delayed
Parking	Human	Reliable Provable	
Route-Tracing	GPS	See Navigation	See Navigation
Access-Control	Human Camera	Non Noticeable Real-time Route Considered	
Unmanned-Vehicle	Physical- Tracks	Less Expensive Adaptable Efficient Scalable	

Table 1. *Reviews for applications on RSR.*

To successfully transmit a relatively large amount of data to a reader and update the tag content, high read rate and high write rate are both essential to RSR applications.

- Eco-friendly materials [15] should be considered during the tag design, and tags should be robust to the environment.
- The installation of tags and readers should be simple and safe to both road structure and vehicles.

Moreover, RSR is a platform to support multiple applications. Therefore, an adaptive hardware and software architecture is necessary for easy system update to support new applications. A layered structure should be a preferred layout for the tag design, the reader design, and the user software design.

### *Research Challenges for RSR Applications*

*Tag Deployment and Read Scheduling* — Briefly speaking, the objective of a tag deployment strategy is to place tags on roads satisfying the application-specific requirements with a minimum cost. Tag deployment needs to jointly consider various factors such as the application requirements, the tag's design, the reader's design, the shape of the lane, and the system's cost. Tag deployment needs to closely cooperate with read scheduling, which determines when a reader should send out its read requests. Current readers are designed to read continuously. Such a reader can easily reach a tag in a neighboring curved lane. To our knowledge, [7] is the only existing work that jointly considers tag deployment and read scheduling for RSR-ANS in a systematic manner. However, this work proposes solutions for straight roads only. We still face a number of important problems that must be addressed. For example, how to deploy tags and schedule reads for curved lanes? What is the complexity of tag deployment and read scheduling when the road topology and distance requirements are given?

*Communication Protocols* — New communication protocols are needed for RSR applications. To be specific, the design objectives of RSR communication protocols should involve the following key points.

- 1 The communication link should be set up quickly because the available contact time is very limited for high speed vehicles with large data receptions.
- 2 The protocol should support multiple packet formats as a reader on a vehicle needs to work with the tags deployed for all RSR applications on all types of road segments.
- 3 Secure write should be addressed at the protocol level such that unauthorized persons can not tamper the data into a tag's memory.
- 4 The protocol should support consecutive readings and writings for RSR-VDE

*Localization* — Location service is one of the most important components of RSR. It is a fundamental element for almost all RSR applications. The problem of localization in RSR involves two subtopics. The first one is the positioning of RFID tags and the second one is the localization of vehicles. Tag positioning refers to the determination of the position of a tag that is deployed on a lane. As tags are deployed in largescale and at wide areas, mobile readers have to be employed for localizing tags in RSR. Then, the reader's position accuracy has to be high because tags are supposed to provide lane level navigation. A possible solution for localizing readers might exist by employing high accuracy GPS receivers such as those providing military level accuracies, which have a position errors of less than 5cm. Alternative solutions for the environments where GPS is not available are also missing. To acquire high position accuracy for lane level navigation, vehicles in RSR are supposed to obtain information from and estimate their positions when passing-by tags deployed on roads. Since the tags in RSR are closer to vehicles, they can provide a higher position accuracy. A vehicle position estimation method for RSR when GPS is not available is proposed in [7]. Its position error is upper bounded by 60cm when considering the tag positioning errors. A localization method that can achieve a higher level accuracy and that can cooperate with GPS is still required.

*Security* — RSR is designed to provide accurate road information to drivers. Major security issues include how to protect the data from being altered by unauthorized persons and how to successfully transmit information to the vehicles passing-by. Several possible attack actions on RSR are listed as follows.

- Reprogramming tags with wrong information.
- Duplicating tags and deploying them on positions where they should not present.
- Deploying malicious tags to jam the communications between legitimate tags and readers.

The first type of attack actions are the most dangerous ones because they do not change the tag deployment in RSR, and thus wrong (or partially wrong) information is hard to be detected by outside observers. As a result, drivers might completely trust it without any hesitation. Therefore, secure programming and user identification protocols to authorize the programming action are essential in RSR. Several secure communication protocols have been proposed to protect tags from secrecy disclosure. To defend against the other two attack actions, an effective way is to periodically schedule tag deployment checking. Duplicated tags could be detected by unique tag ids. Jamming tags could be detected by secure read scheduling.

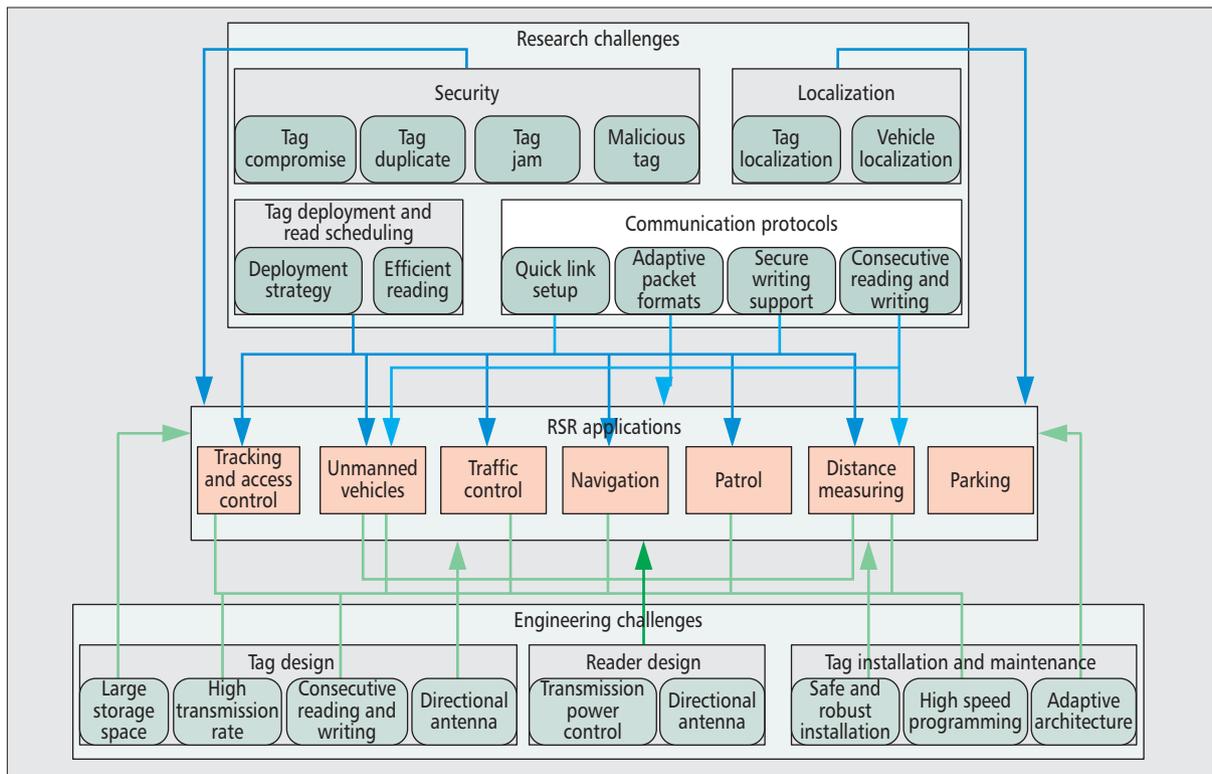


Figure 4. RSR applications and challenges.

In addition to the attack actions mentioned above, RSR may also face security threats from compromised administrators and random data errors caused by environments, which bring in unique challenges of intrusion detection, forensics, and auto recovery.

## Conclusion

In this article, the RFID System on Roads is proposed to improve roadway safety and efficiency. A number of applications are introduced based on RSR. Challenges for implementing RSR and its applications are discussed as well. Figure 4 summarizes the proposed applications, challenges and their relationships.

Upon solving the problems mentioned in the challenges, RSR will be the most informative platform that can provide reliable, precise and near realtime road information to the drivers and road administrators. Through the discussions in this article, one can conclude that RSR's unique features are very attractive and even essential for future transportation systems. Although technology has not been completely ready for RSR, a trend of accomplishment is clear.

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