Abstract—Recently Intelligent Transport Systems (ITS) have acted as an efficient solution for improving the operational performance of traffic systems, reducing traffic congestion, and increasing safety for the travelers. But due to the inclusion of different distributed transport departments, heterogeneous devices, and diverse data sources, the architecture of ITS has become complex and costly. For an efficient and cost-effective architecture, ITS need to have easy and effective mechanisms for interacting among different transport subsystems. Recent technologies such as – service-oriented architectures (SOA), cloud or grid computing, provide a way of building a reliable and loosely-coupled distributed system. This paper surveys the promising solutions for distributed architectures of ITS and discusses opportunities and challenges in the context of ITS for public transport.

Keywords— Intelligent Transport System (ITS); SOA; Cloud Computing; GRID computing;

I. INTRODUCTION

Transportation systems are an essential part of people’s daily life. The increasing dependence of society on an efficient and functioning transportation system motivates the concept of ITS. In order to improve the operational performance of transportation systems it is necessary to increase the use of ‘Information Technology (IT)’ in order to make it intelligent. Therefore, ITS has been defined as [1]: “the application of advanced sensor, computer, electronics, and communication technologies and management strategies-in an integrated manner-to improve the safety and efficiency of the surface transportation system”.

ITS has the potential to ensure greater return-on-investment compared to investment on traditional traffic engineering. This is because according to [6], for many countries, ITS already acts as one of the key factors to expand economic growth, and also helps to reduce unemployment rate. However, this mainly depends on the design of ITS architectures. The development and deployment of ITS is complex because of distributed transportation departments, heterogeneous devices and different types of data which is provided by different sources [2]. As a result, the interactions among different transportation domains become complex and costly. Such types of interactions are however required to facilitate integrated planning, monitoring, and service delivery across large geographical areas. Undoubtedly, ITS has great potential to solve these issues but needs to have a sophisticated architecture to ensure operation at scale, extensive coordination among different traffic control systems from multiple domains and processing large volume of data collected from different sources.

SOA [4] refers to a new paradigm for building reliable distributed systems, where the functions are composed as services and all the interacting components are loosely coupled. Web services [4] for example are a technology for implementing distributed software components using web-based protocols. On the other hand, cloud computing [3] has become a cost-effective and popular technology for using distributed resources efficiently as it allows to bind them together to process a large volume of data or to solve large scale problems. Grid computing [5] is another popular approach for accessing geographically distributed resources such as computer, storage systems, data sources, services, equipments, etc. Research of last few years has shown that the aims of cloud and grid computing are overlapping with the goals of service oriented architectures based on web services. Therefore, it is natural to apply distributed systems technology to solve the problems of ITS.

The aim of this survey is to present an overview on the application of different distributed architectures to the area of intelligent transport systems. We will analyze both opportunities and challenges when applying different architectures to ITS while focusing on public transport services. Especially accessing such services from a massive amount of mobile customers will impose scalability and reliability issues which have to be considered in the design.

The rest of the paper is organized as follows: Section II briefly depicts the most prominent applications of ITS. It also proposes a reference architecture for public ITS. Section III describes proposed distributed architectures for ITS. Section IV analyze the benefits and challenges to develop a distributed architecture for ITS. Section V concludes this paper.

II. COMMON APPLICATIONS FOR ITS AND REFERENCE ARCHITECTURE

A. Common Applications

A wide range of applications can be supported through ITS ranging from ‘Traveler information’ to ‘ICT (Information and
Communication Technology) Infrastructure’. In this paper, we analyze the major areas and core services. According to [5][6], the applications of ITS can be divided into six main categories. A brief overview of the applications is described below. Table 1 provides a summary of the classification.

1) **Traveler Information**: Traveler Information services are considered as the most recognized and core services of ITS. They support the travelers to plan their journey comfortably. They provide two kinds of information: static information, such as geographic data of vehicle stops, transport schedules, etc. and dynamic information, such as changes in the schedules, current weather conditions, closed roadways, expected arrival time of the vehicles, etc. The main target of this kind of applications is to make the trip more comfortable and efficient. Moreover, this category may provide real-time information about the current location of the vehicles. Mainly, three steps are involved in the life cycle of these services: data collection, data aggregation and translation, and information dissemination. In information collection, transportation related data is collected with the aid of different types of devices such as roadside sensors, GPS, camera, etc. Then the collected data is sent to the control center for processing to extract the information that may also assist in future planning. After processing, information is published through different ways such as public messaging, display boards, etc. to help travelers to plan their trips more efficiently.

2) **Traffic Management**: This category includes the applications that emphasize on the devices related to traffic controls such as – traffic signals, ramp metering, etc. The main target of this kind of services is to ensure the efficient use of existing infrastructure. ‘Traffic Data and Operation Centers’ take the data through different instrumentations such as – roadside sensors, GPS, cameras, etc. and generate a structured view of traffic flows to manage the road network efficiently. ‘Adaptive Traffic Signal Control’ service provides an intelligent timing for managing the flow of traffic efficiently. ‘Ramp Metering’ service enables to control the vehicles entering into freeways.

3) **Electronic Pricing and Payment**: This category includes the applications which offer a flexible way of charging the road vehicles. They allow funding to improve the transport systems but also help to reduce the congestion in the urban areas. For example, ‘Congestion Pricing’ service provides a charging scheme for entering into urban areas. ‘Smart Ticketing’ is one of the core and important applications to make the public transport system popular among people.

4) **Vehicle Safety Systems**: This category of applications aims to provide a variety of ways for vehicle safety such as – driver assistance, route guidance, speed control, seat belt reminder, collision avoidance system, etc. As one of the important goals of ITS is to increase the safety of the travelers, this type of applications is considered as the core services. ‘Collision Avoidance System’ provides a way of continuous communication of vehicle-to-vehicle or vehicle-to-infrastructure to avoid collisions at intersection points. ‘Intelligent Speed Adaptation’ service focuses on controlling the speed of the vehicles according to the vehicles’ positions. Most of these applications are provided through a human-machine interface (e.g. on/off-board control unit), to ensure comfort of the users and safe use of this ITS applications.

5) **ICT Infrastructure**: This category deals with underlying technologies such as Global Positioning Systems (GPS), Roadside Cameras, Communications Protocols, Short-range Communications, etc. for running ITS applications.

6) **Freight and Logistics**: This category includes the applications that are related to the tracing and tracking of commodities or animals across the transportation networks.

### Table 1. Classification of ITS Applications

<table>
<thead>
<tr>
<th>ITS category</th>
<th>Core Services for ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveler Information</td>
<td>Static and Real-time Traffic Information.</td>
</tr>
<tr>
<td></td>
<td>Weather Information.</td>
</tr>
<tr>
<td></td>
<td>Real-Time Information about Public Transports.</td>
</tr>
<tr>
<td>Traffic Management</td>
<td>Traffic Data and Operation Centers.</td>
</tr>
<tr>
<td></td>
<td>Ramp Metering.</td>
</tr>
<tr>
<td>Traffic Data and Operation</td>
<td>Intersection Control.</td>
</tr>
<tr>
<td>Electronic Pricing and</td>
<td>Electronic Toll Collection.</td>
</tr>
<tr>
<td>Payment</td>
<td>Congestion Pricing/Access Charging.</td>
</tr>
<tr>
<td>Vehicle Safety Systems</td>
<td>Driver Monitoring.</td>
</tr>
<tr>
<td></td>
<td>Route Guidance/ Navigation System.</td>
</tr>
<tr>
<td>ICT Infrastructure</td>
<td>Collection of Accurate, Reliable Traffic Data.</td>
</tr>
<tr>
<td>Freight and Logistics</td>
<td>Communication Protocols.</td>
</tr>
<tr>
<td></td>
<td>Data Exchange.</td>
</tr>
<tr>
<td></td>
<td>Tracking and Tracing of vehicles, especially, the transports carrying dangerous goods</td>
</tr>
<tr>
<td></td>
<td>or animals.</td>
</tr>
<tr>
<td></td>
<td>Fleet Management.</td>
</tr>
</tbody>
</table>

**B. Reference Architecture for Public ITS**

In this section we propose a generic architecture for distributed ITS for public transport systems while focusing on the mentioned transport applications (Table 1). Our goal is to design an architecture based on the observation that traffic data comes from different transport authorities with different interfaces and format which is a big challenge when a trip includes multiple transport providers. Therefore, it is necessary
to develop an architecture that supports data from multiple sources, and is capable of processing these information and finally deliver the service to the consumers with fine granularity. Within the ITRACT project, we aim to develop a generic distributed platform that ensures flexibility to support a wide variety of existing and new ITS applications, and allows interoperability with external systems. This is important as we want to support scenarios, where mobile users roam around and need to use different services from different transport providers in a transparent way.

Figure 1 depicts the high level view of such a distributed ITS architecture. ‘Integration Platform’ supports the collection of data from a large number of different sources such as public transport databases, taxi databases, etc. It supports both static data such as geographic data of bus/train stops, transport schedules, etc. and dynamic data, such as changes in the schedules, weather conditions, etc. It also supports real-time data such as - updates of vehicle positions. ‘Transformation Layer Platform’ focuses on the processing of large volume of collected data and aligns it into a common format to allow useful operations to be performed on it. ‘Event-Oriented Service Platform’ aims to provide loose coupling among service providers and customers to ensure flexible interaction among different components. It allows mobile customers to receive events they are interested in such as “Inform me when the bus 5 arrives at Karlstad university bus stop”.

Figure 1 also illustrates the interactions among the ‘Service providers’, ‘Service consumers’ and ‘Service producers’. Current systems such as taxi service providers, public transport service providers, etc. are considered as ‘Service Providers’ and denoted as ‘S’ in the figure. Customers denoted as ‘C’ are the consumers of the services through a wide variety of interaction methods such as – web browsers, smart phones, tablets, etc. Some services (such as a service called “Nearby”) uses another service called “BusStops” to get a list of close by bus stops of its current location) can also act as consumers using well-defined APIs. Another entity, ‘Service producers’ denoted as ‘P’ is a specific type of ‘Service Provider’, such as in carpooling “car driver” can be considered as a ‘Service producers’. The platform in the middle acts as a central coordinator among the providers, consumers and producers. It provides distributed data repository which shares, manages, and aggregates the data as produced by the service providers. It also combines the services from different providers according to the requests of the consumers. The distributed storage may be based on e.g. cloud-based data centers or large-scale publish/subscribe systems. The central platform also contains a middleware structure, and ‘portals’ to act as interfaces (APIs) in order to interact with service providers. A challenge will be how to distribute the large volume of real-time data such as bus or train positions, efficiently to a large number of mobile users.

III. DISTRIBUTED ARCHITECTURES FOR ITS

In this section, we provide an overview on the use of distributed IT architectures for ITS. In particular, we focus on SOA-based approaches and compare them with Cloud and Grid based systems.

1. http://www.tract-project.eu/

A. SOA-based Architectures

SOA provides an efficient way of building reliable distributed systems, where the functions are composed as services and all the interacting components are loosely coupled. Moreover, SOA ensures interoperability among different systems which provides the basis for integrating wide range of applications which may use different environments for implementations. Web services are used to implement software components in SOA. Services are accessible through a XML-based protocol, Simple Object Access Protocols (SOAP). Typically, web service architecture includes three entities: ‘Service Providers’, ‘Service Consumers’, and ‘Service Registry’.

MobiGuider [7] is a SOA-based architecture which integrates three different subsystems: Automated Fare Collection (AFC), ITS, and Real Time Passenger Information (RTPI) in one open software platform, ‘MobiGuider_ITS’, an intelligent transport system module which supports dynamic route planning and intelligent scheduling of vehicles through driver assistance, vehicle tracking and punctuality, reporting, data management, operations control, etc. ‘MobiGuider_AFC’ deals with all services regarding e-ticketing such as sales, fare payment, inspection, card management, etc. ‘MobiGuider_RTPI’ provides services to process and publish real-time information about the trips such as trip information, detour information, etc. MobiGuider includes two major parts: ‘On-board Computer’ and ‘Traffic Control Centre’. On-board computer manages all equipments in a vehicle and allows it to communicate with the traffic control center. The traffic control center is the core of the traffic control system, responsible for monitoring the whole transportation data.

Z. Changyu et al. [12] present an intelligent traffic management data center for Beijing based on SOA. It supports high-level decision making, and is capable of changing operations for transport management. The main argument behind the selection of SOA for [12] is that it has the standard features such as - distributed architecture, service-based
applications, platform independence and wide granularity. The architecture of the Beijing Traffic Data Centre aims for comprehensive information integration, efficient information sharing, proper data exchange, supporting on-demand services, for a cost-effective standard model for future development. The process planning for the architecture is divided into two phases. The first phase analyzes existing traffic information and data models and develops a standard application for data accessing. At the second phase, the existing system is completely transformed into a unified SOA structure. The SOA framework includes four layers: data service layer, application service layer, integrated service layer, and external published integrated layer.

In-Time [13] defines a common infrastructure for road and transport users in order to provide an efficient environment and to operate ‘Multimodal Real Time Traffic and Travel Information (RTTI)’ services. The In-time project mainly focuses on middleware architectures, a service-oriented architecture which provides different types of data/services related to traffic, public transports, weather, dynamic route planning, etc. Traffic Information Service Providers (TISPs) provide their value added services to the end users through the access of Regional Data/Service Server (RDSS) data. A standard Commonly Agreed Interface (CAI) is considered as the fundamental component of this middleware infrastructure. CAI provides an identical platform to access all traffic related data through a single point and exchange these data via a number of reliable information channels. The interoperability between different local data/service sources and TISPs is the key feature of the In-time architecture. In order to support this feature, In-Time has adopted a service-oriented distributed architecture, where all the data/service providers (local transport authorities) and transport information service providers (navigation service providers, journey planning service providers, etc.) are interlinked through the B2B CAI. The In-time CAI provides a standard way to access real-time multimodal travel and transport data and services provided by the RDSSs. TISPs can access and encapsulate all the local services in a specific geographical area through CAI and offer these to the end users as value-added services. CAI is built on top of the In-Time middleware architecture, with the aim of transforming local data format to a standard common format.

C. Li [14] identifies the problem of ensuring quality of traffic information because of a large number of Travel Information Service (TIS) providers. [14] introduces the idea of traffic information service based on SOA, which integrates services or data from different providers in order to publish reliable, accurate and complete information for the travelers. With increasing numbers of ITS provider organizations, it has become difficult and confusing for the end users to select the accurate service as different providers offer the same service in different formats. On the other hand, it is also not possible to combine different services from the same provider. Two mechanisms are thus required: one is to construct a distributed architecture to integrate different services from different providers; and the other is to introduce an uniform set of standards to classify and present the description of ITS, so that it is possible to collect and integrate different types of transport information into public-oriented services. The TIS system based on SOA provides the interoperability with other systems so that it can easily integrate services from different providers. In [15], C. Li et al. address the connections among three actors in a transportation domain - travelers, vehicles and roads, and propose an innovative way of classify TIS services. All types of services are presented using eXtensible Markup Language (XML) as a common format, which is easily understandable by both human and machines.

X.-L. Lu [16] presents the design of GIS (Geographic Information System) transportation system based on web service technology. The main objective of the GIS-T web services is to support ITS applications with spatial data and processing of several tasks related to geo-processing such as – detect duplicate addresses, display maps, planning routes, etc. without any requirement for integrating GIS instruments. Different departments related to the transportation system can use the GIS-T web service to build a collaborative work environment, which makes the coordination easier and efficient. While it is challenging for a traditional GIS software to support all the requirements of ITS with a single platform, GIS-T web services technology has offered an effective solution to handle this problem.

B. Cloud-based Architectures

Cloud computing provides an efficient way of utilizing geographically distributed resources through virtualization and distributed computing techniques. The main idea behind this technology is to reduce operational cost, to increase sharing of resources, and to enable easy access to the resources through different client platforms.

W.-H. Cai et al. [8] present a modern intelligent transportation system based on cloud computing while integrating information technology, control technology, sensor technology, communication technology and system inclusive technology. It considers both technology and management perspective, and describes the architecture as well as the procedure of building a cloud transportation system (CTS). Cloud-based transportation system combines cloud computing, internet of things, high performance computing, service-oriented architecture and relevant intelligent technology. The authors suggest that the modern cloud-based transportation system is extremely effective, economical, and knowledge-based because it supports efficient and cost effective integration of heterogeneous computation resources and distributed storages. Additionally, SOA ensures seamless coordination and communication among different domains of transport systems. The cloud-based transport system involves existing departments of public transportation: security management, vehicle management agencies, urban transportation companies, communication companies, etc. and aims to ensure comprehensive, multiple-department-driven secured public transport. The system mainly includes three entities, transportation-related service providers, platform operators, and customers of these services. These entities are integrated through a ‘Traffic Information Bus’. Service providers may include software providers, ITS service integrators and providers, communication service operators, etc. ‘Platform operators’ may include traffic departments, cloud computing data centers, etc. ‘Consumers’ may include
traffic managers, vehicle or driver, traveler, etc. The overall architecture of CTS consists of three layers and two wings. The layers are - infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). The wings are - cloud transportation platform/system standards and specification, and cloud computing console. IaaS provides a cost effective and efficient IT infrastructure to meet the demand of huge data management and storage capacity. PaaS and SaaS together provide a platform, which is able to easily integrate information from different sources and makes the resources more abundant.

P. Jaworski et al. [9] describe a traffic control system for metropolitan areas based on cloud computing. Its primary objectives are to increase the operational performance and safety of the travelers, and also to reduce energy consumption and carbon releases. For routing, the system integrates geographical addressing and cloud-based service discovery mechanisms. Geographical multicast addressing uses a simple addressing mechanism by pointing to all the vehicles in a particular region. A software component, ’Intersection Control Service (ICS)’ is attached with an off-board control unit that manages the intersection points. Each vehicle is treated as an individual cloud service and cloud-based technology is used to identify the vehicles. ICS collects traffic data from different points, such as road intersection points and vehicles, and improves the traffic throughput by creating a dynamic route based on short time predictions and current road situations.

Z. Dong et al. [10] present an Internet-based Advanced Traveler Information Service (AITS) based on Internet technology. AITS supports travelers with high level operations such as planning, analysis, and decision making in order to make the journey safe, comfortable, convenient and well-organized. It provides accurate real-time information on weather, vehicle schedules, road conditions, or information about construction points to the travelers. Pieces of information provided by AITS, are mainly divided into three categories based on traveler types and information types – Pre-trip, En-route and After-trip information services for the single traveler, group of travelers and vehicle drivers. The architecture of AITS is divided into three major modules: Information collecting, processing, and releasing. [10] presents the idea of TIS based on Internet and combines Focused search engine, Cloud computing, Social Network service (SNS) and Mobile Internet. Cloud computing is used for information processing, utilizes the computing resources efficiently and allows to build data center with high computing performance. Cloud computing based data centers not only provide accurate real-time data but also save a large amount of money for implementation and maintenance.

On-demand bus service is described as, “A demand responsive transit service where the vehicles transport users after they reserve their seats, and the vehicle does not move if there is no reservation”. On-demand bus service is already introduced in many cities but the high operating cost makes it less popular. K. Tsubouchi et al. [17] describe the ‘innovative on-demand bus system’ while considering the cost issues. It is based on cloud computing technology. The proposed system includes four major modules: schedule calculation system, communication devices, reservation interface and database. The main advantage of this system is that the software blocks are implemented at the remote servers. Therefore, the local transport authorities can run the service without spending money to establish their own servers. As a result, the operating cost of the system is reduced. Moreover, the schedules of ‘innovative on-demand bus system’ are efficient as well as ensure high quality due to automatic updates of the timetables during reservations.

C. Grid-based Architectures

Grid computing utilizes the resources of multiple computers to solve a particular problem cooperatively, without tight coupling. In grid computing, a large problem is divided among several workstations in order to ensure the best use of available resources in a cost-effective way. Grid computing can be achieved through the resources within an organization or may be as a collaboration of different resources from multiple domains.

X. Tao et al. [11] present a module for ITS, Shanghai Transportation Information Service Application Grid (STISAG), by utilizing the concept of Grid, SOA and Web Service technology. STISAG mainly focuses on the problem of traffic jam in Shanghai and offers diverse types of real-time traffic and travel information services to the end users. The model integrates data or services from different traffic sources, such as Shanghai Taxi Company, Shanghai Bus Company, and Shanghai Transportation Information Centre. Moreover, the model integrates Shanghai Grid nodes, to process real-time transport information and to store the large amount of traffic data. At the network level, STISAG has two network nodes - Traffic Intranet, and Shanghai Grid. Traffic Intranet connects diverse transportation branches via 100M-network and provides a platform to process and publish traffic information on-demand. All the nodes in Shanghai Grid are connected through the Internet and ensure computation and storage of a large volume of traffic data. Tongji University, a core grid node, performs information processing and service computation. It connects Traffic Intranet, and Shanghai Grid to organize STISAG. STISAG divides the whole model into five layers: Traffic Information Collection Layer, Traffic Information Integration Layer, Traffic Foundational Function Layer, Traffic Service Integration Layer, Traffic Information presentation Layer. Traffic Information Collection Layer includes a wide range of devices for collecting different kinds of traffic data from different sources, such as data gathered through GPS. Traffic Information Integration Layer integrates heterogeneous traffic data, stores information and implements an interface to access these data. Traffic Foundational Function Layer implements functional components of STISAG. Grid technology is used to ensure proper distribution of computation resources in order to process large volume of real-time data. Traffic Service Integration Layer, based on SOA, provides integration of various services from different transportation departments and offers a variety of on-demand services related to traffic information. Traffic Information Presentation Layer provides an efficient and easy way of publishing traffic information of STISAG so that users can access information at any time through several types of terminals, such as mobile phone, computer, PDA, etc.
In Table 2, we classify the papers according to the technology used for ITS architectural design. It is clear from Table 2 that the goals of using cloud computing, grid computing, or service-oriented architecture in the context of intelligent transport system overlap to a certain extent. The primary goal of using the mentioned technologies is to improve the operational efficiency of transport systems at lower cost.

<table>
<thead>
<tr>
<th>Services</th>
<th>SOA/WEB SERVICE</th>
<th>CLOUD</th>
<th>GRID</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIS</td>
<td>[7],[8],[11],[13],[14],[15]</td>
<td>[8],[10]</td>
<td>[11]</td>
</tr>
<tr>
<td>GIS</td>
<td>[16]</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>RTTI</td>
<td>[7],[13]</td>
<td>[10]</td>
<td>—</td>
</tr>
<tr>
<td>TCS</td>
<td>[7],[11]</td>
<td>[9]</td>
<td>[11]</td>
</tr>
<tr>
<td>OBS</td>
<td>—</td>
<td>[17]</td>
<td>—</td>
</tr>
<tr>
<td>TDS</td>
<td>[12]</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>


IV. OPPORTUNITIES AND CHALLENGES

The deployment of an intelligent transport system delivers a number of benefits which make the transport systems more efficient, reliable. This motivates the public planners to increase the funding for transportation development. According to [6], for many countries, ITS already acts as one of the key factors to expand economic growth, and also helps to reduce unemployment rate. Although ITS has significant advantages, high operational cost blocks its wide adoption. We strongly believe that a distributed ITS architecture will reduce the overall system cost and hence, attract people to adopt it. Some key benefits of use a distributed architecture such as SOA, cloud, grid for ITS are mentioned below.

- **Loose coupling and high interoperability among heterogeneous and distributed traffic departments**: One of the important characteristics of ITS is that it includes a large number of subsystems such as – traffic control centers, different data sources, on/off-board control units, etc. Therefore, for an efficient system, ITS should have an effective mechanism to interwork among these different departments. SOA has the capability to build a distributed model [18] which is loosely coupled, standard-based, and protocol independent. Moreover, SOA also ensures smooth coordination among different domains of transport, and interoperability with external systems.

- **Reducing pressures on hot spots**: ITS needs to deal with large volume of real-time information processing, especially in the urban areas during peak hours. Therefore, there is a great possibility of degrading operational performance at that time. Grid and cloud computing technology offers a way to distribute tasks to different resources for balancing the load properly. Therefore, the system can utilize the available resources, and provide the needed scalability which helps to speed up performance.

- **High performance computing and storage resources**: For an efficient ITS architecture it is required to build resources with high computational power and large storage. ITS needs to collect large volume of data through different instruments, process those data efficiently, and finally disseminate this information on time to meet the requirements of the travelers. Cloud computing technology provides the opportunity for ITS to compute and store traffic data efficiently on clusters of distributed resources.

However, most of these technologies have their own shortcomings such as – security issues, support for mobility, etc. Therefore, before using or integrating these technologies into ITS, we need to identify the challenges. Some key challenges are presented below.

- **Technological developments**: Although cloud computing has gained interest of a large number of researchers, there is no common standard for hardware selection. However, for the service providers there is very little scope to directly access the hardware resources provided by the cloud providers. Moreover, there is no standard for cloud interoperability that guides how data is exchanged across different cloud providers. However, in ITS it is important to ensure interoperability between clouds because depending on demand, services may require data from more than one cloud. This may require efficient interworking of cloud providers under tight real-time constraints.

- **Mobility of users**: Typically, the users of ITS move through different geographical locations and use different equipment through different networks to use the services. In ITS, mobile users need to access real-time information such as vehicle positions while on the move. Users’ mobility should not interrupt or delay accessing the time-critical transport services. Hence, distributed architectures should efficiently support the mobility of end users. However, current cloud-based architectures do not design their service delivery models by taking into account the concept of user mobility under tight real-time constraints.

- **Performance**: The performance of cloud or grid-based architectures can vary for various reasons such as network congestion, accessing data from different sources, etc. In grid-based architecture, a high-speed internet connection is required to connect all the resources. ‘Vertical scalability’ is the capability of an application to keep its performance level high when large numbers of requests are received concurrently. ‘Vertical scalability’ is also a challenging issue that needs to be handled properly when designing a cloud-based architecture to increase the performance.
• **Security:** Security is the most important factor that blocks broad deployment of cloud-based architectures. In order to encourage the transport service providers to store their data on clouds, it is necessary to ensure data storage security. Moreover, it is important to defend against Distributed Denial of Service attacks (DDoS) to ensure the on-time availability of transport services to the consumers.

V. CONCLUSIONS

Intelligent transport system is an efficient way of improving the efficiency and services of transportation systems of any country. However, the operational performance level of an ITS mainly depends on its architectural design. This paper provides a survey focusing on the use of distributed architectures for intelligent transport systems based on SOA, Grid and Cloud Computing. We have illustrated a reference architecture for distributed ITS and classified the most important and core applications for an ITS. We have described a number of existing and potential solutions based on recent and promising technologies such as – SOA, Cloud or Grid Computing. We have demonstrated the necessity of development and deployment of a distributed ITS with particular focus on its opportunities and relative challenges. Especially, architectures need to provide support for massive amount of mobile customers with proper scalability and reliability.

ACKNOWLEDGMENT

This research was carried out as a part of the project ITRACT, funded by InterReg IVb NorthSea region programme.

REFERENCES