Low-cost computational systems applied to physical architectures in public transportation systems of intermediate cities

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Abstract. Public transportation systems in many cities of Latin America must employ physical architectures of intelligent transportation systems for the operation and control of passenger transportation vehicles. However, the high cost of specialized computational systems for this physical architectures in one of the higher impediments to the integration of this systems in the vehicle network. For the purpose of this work, is necessary to ask what are the currently low-cost computational systems used in vehicular applications. In this paper we made a documentary research to analyse the current computational systems associated with the physical architecture for public transportation in intermediate cities. We analysed collected information following the three points of methodological development for a documentary researches. Results shows that the use of low-cost computational systems for data capture in vehicles, the use of millimetre waves in the electromagnetic spectrum for data transmission by means of mobile communication networks, and the adoption of international standards, are viable alternatives for the integration of technologies into physical architectures of vehicle networks, in order to improve the operation of public passenger transportation systems in intermediate cities in Latin America.

1. Introduction

Public passenger transportation is shared by most of the people of a city and directly affects their welfare. This system responds to changes in society's mobility habits, to the increase in available options, to vehicle congestion, and to the environmental impact caused by the vehicle fleet [1,2].

Actually, many cities do not have efficient and effective public passenger transportation systems. In India, the different means of public passenger transportation in intermediate and small cities are provided by informal transportation operators that struggle to meet the mobility demands of the local population [3]. In Latin America, the motorization rate has increased considerably in recent years; for example, in Colombia the annual increment of motorcycles is 14.7% and that of cars is 6.6% [4].

However, in Latin American cities the mobility of people by public transportation continues to predominate over travel by individual motorized transportation. For example, in the cities of Lima-Callao in Peru, 53% of travel is by public transportation, 21% by private transportation and 26% by non-motorized means (walking/bicycling) [4]. Therefore, the challenge in Latin America focuses on
integrating public transportation systems at various levels to respond to mobility needs and ensure the sustainable development of intermediate cities.

In the Colombian context, the strategic public transportation systems (SETP, Spanish acronym) were designed to improve and integrate public passenger transportation in intermediate cities. These systems must operate under parameters that respond to quality factors in the provision of the service. In addition, SETPs must integrate information and communication technologies (ICTs) to optimize fleet control and management, electronic payment collection, road safety, and the delivery of information to users [5,6].

However, SETPs do not fully operate in the cities selected for their implementation because of delays in the adaptation of road infrastructure and the high costs of computer systems that must be integrated into the physical architecture of operation and control of the system. For this reason, it is necessary to work to design solutions using dynamic and low-cost computational systems that offer an improvement to these systems [7]. Solutions to designed should base the latest trends in intelligent transportation systems (ITS) and ICT. Thus, to design an efficient solution, it is necessary to ask what are the low-cost physical architectures used in the operation of public transportation systems.

To solve the previous question, in this work we made a documentary research to analyse the current computational systems in the data collection of public transportation vehicles, from the low-cost approach. Documentary research contemplated the study of information in ITS, mobile communication networks and millimetre waves applications for this systems, and computational systems related with physical architecture of an ITS. Results of this analysis allowed us to identify current trends in low-cost computational systems and to study the advantages of their implementation in public passenger transportation systems. With this we can recognize the added value that these systems can contribute to the intermediate cities of Colombia and Latin America.

2. Intelligent transportation systems

An ITS is defined as the application of advanced technologies in sensors, computers, communications, and management strategies, to improve the safety, efficiency, and sustainability of the road transportation system [8]. In an ITS, ICT is used to solve problems in conventional transport systems without increasing the capacity of the road infrastructure network [9].

ITS combines various areas of engineering (transportation, systems, telecommunications, environmental, financial, among others) with the purpose of seeking efficiency in transportation, mitigating environmental impacts, and safeguarding human life through road safety. Day by day these systems take a lot of peak and their demand and development in public transportation increases. Table 1 shows the evolution on time of ITS, where the evolution is classified in five generations in two last decades, and its include the infrastructure and technology's characteristics in each generation.

| Generation  | Period       | Characteristics                                                                 |
|-------------|--------------|----------------------------------------------------------------------------------|
| 1 First     | 2000         | Based on unidirectional infrastructure.                                          |
| 2 Second    | 2000-2003    | Bidirectional communications.                                                     |
| 3 Third     | 2004-2005    | Automatic vehicle operations; automated and interactive system operations; system management. |
| 4 Fourth    | 2006-2019    | Multimodal incorporation of personal and vehicular mobile devices; infrastructure and information networks for system operations; personal contextual mobility solutions. |
| 5 Fifth     | 2020-        | Cooperative intelligent transport systems (C-ITS); improved vehicle-to-infrastructure (V2I) communication; pedestrian safety; gamification. |

In the implementation of an ITS project the operation and maintenance costs represent between 40% and 55% of the total budget to be invested. Therefore, is important to take into account the system life-cycle, including the state of the technology, operation, maintenance, and replacement of equipment [11].
2.1. Information on intelligent transportation systems
The ownership of the information generated and stored in a transport system must be defined during the implementation of the ITS [11]. For information to be useful in an ITS, it must have the following characteristics: easy to understand, concise, reliable, up to date, quickly captured, useful to the user, not open to different interpretations [12]. Figure 1 shows the elements that make up an ITS-related information system, grouped in the three-phases of information flow in ITS systems (data collection, information processing, message delivery), and include the mediums of data capture/distribution.

Figure 1. Elements of an information system for ITS; adapted from [12].

As the amount of data generated in an ITS increases, Big Data analysis for ITS provides a new technical method that benefits the system in: resolution of information storage and management problems, efficiency of system operation, and improvement of the system's security level [13].

2.2. 5G communication networks
5G's usage patterns are not limited to mobile broadband. 5G is expected to support a diverse range of use cases in three categories: enhanced mobile broadband (for wide area coverage and critical points); ultra-reliable and low-latency communications (for intelligent transportation systems, V2X vehicle-to-everything connection, transportation security, etc.); and machine-type mass communications [14].

With the development of 5G communication systems and software-defined networks, the performance of vehicle networks can be improved and new vehicle network applications will be required. In [15], a vehicle network architecture is proposed that integrates 5G communication technologies, including millimetre-wave transmission to connect users inside vehicles. The main contributions of the 5G vehicle network proposed in [15] are: be integrated by software defined networks, cloud computing and foggy computing technologies to form three logistic planes (application, control, data); the fog cell structure is proposed at the edge of the vehicular networks; there is a minimum transmission delay of vehicle networks considering different vehicle densities, so the performance of fog cells is better than the performance of traditional transport management systems.

2.2.1. Millimetre waves channels in 5G. According to the wavelength equation (represented in Equation (1), where $\lambda$ is the wavelength, $c$ is the wave’s propagation velocity, and $f$ is the frequency), exists an inversely proportional ratio between the wavelength and its frequency. In electromagnetic waves of frequency range from 30GHz to 300GHz, wavelengths are around 1 to 10mm. These waves are known as millimetre waves (MMW) and these waves are part of the so-called microwaves (waves in the frequency range from 300MHz to 300GHz).

$$\lambda = \frac{c}{f}. \quad (1)$$

One of the most important attractions of MMW today is that at such high frequencies the available bandwidths are much higher, allowing the installation of radio links with multiple gigabits per second
capabilities. Mobile wireless networks must cope with the increase in capacity needed to meet the current demand for services. With the implementation of MMW channels in 5G, an alternative can be provided to face this type of challenge.

In addition, MMW channels experience some different propagation effects, such as remarkable atmospheric absorption for longer links, reflection from surfaces with a severity comparable to wavelength and poor diffraction. Therefore, the attenuation and dispersion characteristics, which determine the performance of the 5G system, will be significantly different [14].

2.2.2. Electromagnetic spectrum regulation for 5G. The introduction of 5G can take place in multiple frequency bands. The bands (in GHz) 24.25-27.5; 31.8-43.5; 45.5-50.2; 50.4-52.6; 66-76; 81-86; were approved for study, in order to provide a substantial amount of new bandwidth. The new spectrum can be managed through licensed access as is the current case [14].

3. Methodology
In this work, a series of stages were adapted based on the methodological proposal followed by [16-18]. Methodological application in this work addressed the following three basic aspects: approach, type of research, and process theoretical construction. The documentary research required the search of previous investigations related with ITS and public transportation that would allow the recognition of low-cost computational systems for both entities. We analysed information that were studied from de viewpoint of their application in ITS, specify in the recognition of low-cost computer systems for these technologies and the advantages of its integration. Considering this data, we defined the following points to the development of this research:

- Recognize the low-cost computer systems for ITS, the currently trends and categorization of technologies for these systems.
- Identify the current state of ITS computational systems in the physical architectures of public transportation systems.
- Determine how low-cost computer systems for ITS can influence the provision of service through the appropriate implementation of technology.

4. Results
We analysed the data from [11,19-21] and selected the information concerning the computational systems associated with the physical architecture of the intelligent transportation systems, which can be applied to intermediate cities as an alternative to improve the public passenger transportation systems.

Costs can be reduced by using sensors and communication media that are more cost-effective than using traditional technologies [20]. In the implementation of ITS projects, sensors in the physical infrastructure can be replaced by in-vehicle sensors or by smartphones. An example of data capture using a smartphone in an urban bus can be found at [22], where geolocation and vibrations of the bus were measured with the data delivered by GPS and accelerometer from smartphone through a mobile application. In turn, data can be transmitted from vehicles to data centres via 3G, 4G, and soon 5G mobile communications networks.

Table 2 shows the comparison of four scenarios considered for the implementation of physical architecture in an ITS. In three qualitative terms (high, medium, low), this comparison evaluates the performance levels and costs of the scenarios studied. Analysing the scenarios in two last rows where are implemented smartphones as computational systems for data collection in ITS, we found that correspond to low-cost options because costs to user and to operator are lower with an acceptable performance of the system. When the vehicle data comes from a smartphone, this computational system can be seen as a complete low-cost model since the device is self-sufficient to collect, transmit, receive and display data information. Additionally, connecting to the socket on board diagnostics (OBD) via radio wave interface (e.g., Bluetooth) increases data fidelity and this enhanced data can be transmitted via the smartphone to data centres. In both cases, the subsystems involved are the vehicle, the driver's
device (smartphone) and the data centres. Figure 2 shows the physical architecture of the application of subsystems involved in the above-mentioned low-cost models, representing the flow data from vehicles to data centres using smartphones’ sensors or OBD socket as data collectors. In first case, when data is collected directly by smartphone this is considered nomad subsystem, and information starts its flow from user’s device. In second case, when data is collected from OBD socket this is considered vehicle subsystem, and information starts its flow from vehicle's computer system.

Table 2. Comparison of four scenarios for physical architecture implementation and technologies in an ITS.

| Technologies          | Data collection | Data transmission | Information dissemination | Performance | Cost to user | Cost to operator |
|-----------------------|-----------------|------------------|--------------------------|-------------|--------------|------------------|
| Infrastructure devices| Wired (ADSL)    | Variable messages system | Middle | Middle | High | Low | Low | High |
| In-vehicle sensors DSCR/ITSG5 | Vehicle dashboard | High | High | Middle | High | High | Low | Low |
| Smartphone sensors   | 3G/4G/5G         | Smartphone      | Middle | Low | Middle | Low | Low |
| Smartphone connected to OBD socket | 3G/4G/5G | Smartphone | High | Low | Middle | High | Low | Low |

![Wired communication of wide-range: centres to centres (ADSL)](image-url)

![Wide-range communication: centres to vehicles - (3G, 4G, 5G) - to users](image-url)

Figure 2. Application of subsystems with data collected in two scenarios (smartphone, OBD + smartphone).

Deployment of the 5G mobile phone networks will facilitate the data transmission discussed in the previous paragraph. The implementation of software-defined networks and the use of millimetre-wave channels in the physical and logical architecture of mobile communications are an improvement on communications technologies. Along with increased processing power, this will increase the speed of data in transportation systems.
4.1. Adoption of international standards
Most Latin American countries have not adopted standards to implement ITS in public transportation systems [11]. The adoption of standardized architectures is necessary, as it promotes flexibility, scalability, and system integration. Therefore, the selection must be made taking into account the public policy objectives, the existing computational systems, and the functional and non-functional requirements of the physical and logical architecture to be implemented. Table 3 shows the advantages of adopting international standards in the implementation of ITS in a transportation system, where most highlights contributions of standards are reducing the time and costs of implementation, and mitigating premature obsolescence of technology at computational system. In the description, there is an extended explanation of the contributions provided by each advantage included in the table.

Table 3. Advantages of implementing standards in ITS.

| Advantage                                      | Description |
|------------------------------------------------|-------------|
| Encourage plurality and competition of suppliers | With a set of robust standards in place, suppliers begin the process of building technologies that meet those standards. In addition, they seek to add additional functionality and features that allow them to offer a differentiating factor from other providers. The existence of multiple suppliers providing technologies that meet standards encourages competition. Competition allows the reduction of the costs of acquisition and renewal of ITS systems. |
| To help reduce the time and cost of implementation | The existence of technologies already designed and approved by international standards, favours the availability and time of acquisition of them. In addition, as mentioned above, it fosters competitiveness and cost reduction in the acquisition and renewal of equipment. |
| Mitigating premature obsolescence of the technology platform | ITS systems represent significant investment costs for cities. This is why the life span of the equipment is a decisive factor in its acquisition. Acquiring equipment that meets international standards allows suppliers to ensure that the equipment remains operational and functional throughout its life. |
| Reduce system life-cycle costs | Maintenance of the technological platform of the equipment represents an important component in the life cycle costs of ITS systems. Have certainty of compliance with standards of the technology platform, allows technology operators to be able to operate their systems without the need to learn a different set of operating parameters for each component of the same type of technology architecture, reducing training and maintenance costs. |

5. Conclusions
In this paper we identify the current trends of low-cost computational systems related to the physical architecture of intelligent transport systems. These systems are mainly based on information and communication technologies, which are in continuous development. Additionally, the advance of ICT offers opportunities to create new value-added services in public transportation systems based on existing ITS applications.

In ITS services and applications, data are a fundamental part of the process: they are collected, transmitted to information centres, processed and disseminated to end users (drivers, public transportation users, among others). Transmission over millimetre-wave channels and software-defined networks, typical of the 5G network deployment for mobile communications, will increase the speed of data transmission from vehicles to the central information subsystems of the vehicle network.

With the identification of low-cost computational systems for data collection (e.g., the use of smartphones for vehicle data capture), alternatives for implementing ITS projects in intermediate cities where their adoption is necessary arise. These trends, under international architectures and standards, can supply several of the operation needs of public transportation with a lower investment cost in these populations.
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