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Abstract. The beginnings of intelligent transport systems are motivated by mobility enhancement for citizens to meet socio-economic requirements. The integration of road safety is rapidly highlighted as a necessary aspect for the development and evolution of ITS. This paper presents the chronological evolution of several research themes from the first programs around the world. Through ITS historic evolution, a diversity of technologies and innovative solutions were developed. Among these advances, we consider guiding systems, Vehicle and Intelligent Highway (IVHS), traffic management, electronic payment, information on public transportation, traveler information systems, commercial vehicles etc., Communication technologies play a crucial role in many ITS solutions and particularly for road safety. They were considered for efficient incident management first and nowadays they represent an important base for connected and autonomous vehicles success. Among processing techniques for ITS services optimization, the role of metaheuristics is highlighted.

Keywords: Intelligent transportation systems, traffic management, communication technologies, road safety, metaheuristics.

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1. Introduction

ITS have emerged in the United States in the sixties with road safety and mobility as primary objectives. ITS has provided numerous solutions to problems for the transportation network management in general. Nevertheless, several improvements are still needed and there is room for improvement especially in terms of road safety although several solutions are developed in this topic.

Numerous research and development contributions on emerging technologies have improved transport networks QoS. However, there are still big challenges at different levels and many research issues remain open. These may include technology deployment policies and also their integration for optimum overall performance. We present here an overview on ITS history and associated advances on technologies and emergent services.

This paper is organized as follows. Sections 2 presents a brief history of ITS evolution. Section 3 gives an overview on ITS expansion around the World with research activities evolutions. Section 4 provides an insight into the research in ITS especially those focused on communication technologies considering road safety requirements. Section 5 provides a conclusion and future directions.

2. An overview on ITS Historic evolution

2.1 The beginnings of ITS

Intelligent transportation systems are initially motivated by access problems to workplaces from remote locations. Very rapidly, the problem of traffic management becomes complex, given that solutions based on the construction of new infrastructures cannot be viable continuously. Traffic issue have then held important positions at the ITS.

2.2 Concerns that led to the first ITS applications

From the very beginnings of ITS, traffic congestion problems arose. The overall congestions of transport infrastructure require significant socio-economic cost in terms of air pollution and fuel consumption as well as transport users waste of time. Due to the large population and the number of vehicles growth, there has been a rising level of interest in urbanization in developed countries.

As a direct impact of these concerns, the intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) established a Federal program to research, develop, and operationally test Intelligent

Transportation Systems (ITS). [1]. This program has been designed to facilitate the deployment of ITS technology with the objective of improving the efficiency, safety and convenience of transport [1].

2.3. First ITS systems

In Japan, the first appearances of ITS date from the 1960s to the 1970s. Special attention was paid to automotive traffic control such as CACS: Comprehensive Automobile Control System [3]. Among other first ITS systems, we consider here the Electronic Route Guidance Systems (ERGS) dedicated to guidance. At the beginning, these systems were based on centralized processing. A main reason that make them limited due to numerous technical constraints. Moreover, centralized congestion processing has hampered the achievement of expected results.

With respect to ITS in USA, the first results of research and development have also considered electronic route guidance systems (ERGS). These systems are based on electronic equipment's which are integrated in vehicles and roads intersections. [2]

Guidance techniques are based on routing instructions displayed [2]. Drivers are allowed either to continue at intersections on the same directions or to take new directions according to optimal routes. Routing problem solving techniques are considered in this system to find optimal routes. The solutions of ERGS to find the best routes applications include both software and hardware components. In recent developments, communications with drivers play important roles to solve complex routing problems.

2.4. Impact of economic factors for ITS development

In the United States, the beginnings of ITS were marked by important challenges for citizens who are in social wellbeing. They have difficulties in accessing potential work due to the lack of mobility means and facilities. Discussions on solutions to poverty lasted several years before providing solutions based on the improvement of mobility [4].

In view of these economic situations, a federal law on transport efficiency (ISTEA) was drawn up in 1991. This law concerns personal responsibilities in relation to work opportunities. It made it possible for many citizens to mobilize more in relation to employment [4].

The program related to this law involved the development of ITS research and development including testing [1]. Such a law has also been designed to facilitate the deployment of technologies to improve road safety and save lives. Other objectives concern the ease of access to transport and the increase in productivity [1]. Many ITS projects have been supported by this program [1].

The last decades are characterized by new technologies for advanced ITS solutions. Following early ITS developments, there have been many developments distributed geographically. From the first decades of the 2000s, intelligent transport systems ranged in different countries in different continents. Applications that followed the electronic guide are presented by investments in the embedded road information followed by automated highways in the late 90s to develop multimodal and especially road safety solutions.

3. First ITS development extensions across the world

3.1 Program overviews of some countries around the World

Numerous countries around the world have developed ITS-based programs to develop solutions for their transport networks operations efficiency. In South Africa, the annual number of road traffic fatalities experienced steady growth. Many measures based on ITS solutions have been defined to deal with such dramatic situations. In 2005, the number of deaths was 15,393 vs. 14,135 in 2004 [5].

A similar situation in South Korea led to the establishment of an ITS-based program. For this case, a 20-year blueprint was ventilated representing National ITS Services [6]. The main services define traffic management, electronic payment, information on public transportation, traveler information, commercial vehicles. The mission of the national ITS is to create a network of traffic systems that can facilitate interactions and interconnection between major cities in South Korea [7]. The ITS services program is made up of three phases. **Phase 1**: training at institutions level. **Phase 2**: training for industrialization and **Phase 3**: Establishment of connections between the previous phases in order to ensure the compatibility and efficiency in ITS planning operations for advanced technologies.

In China, the need to develop ITS is particularly related to road safety management. ITS technologies are then examined and associated with various national situations. The main objective is to solve road safety problems. [8].

3.2 Evolution of research themes for ITS

From the beginning of ITS, the main technical themes were particularly related to the traffic management and drivers guide systems. Observing the evolution of ITS concerns and developments over the time, new themes such as travelers' information, transport management systems, human factors and road safety have emerged and also gained prominence. Research and development themes on ITS are developed according to several needs which have to be completed for the good functioning of the transport networks.

Research themes defined for ITS include optimisation and problem solving related to road safety, optimisation of fluid mobility and optimisation of existing infrastructures managements [9]. Other research themes in ITS are defined by intelligent vehicles, commercial vehicle operations, traveler information, and intermodal freight [10],

Traffic control & management is considered as one of the most important research topics in ITS. Its development will continue to set new traffic management generations [11]. On the other hand, communication technologies play a critical role in the success of the deployment of numerous solutions. Such communications are mainly found in communications from vehicle to vehicle and from vehicle to infrastructure.

The extent of the road safety problems and the potential benefits of ITS solutions, have justified an intensified research in this area. Many studies on road safety are related to incident management. One of the first technologies for incident detection based on loops installed on road

was developed in 1973 [11]. The evaluation of accident data has shown that electronic stability is an important factor in reducing individual vehicle collisions. Thus, sophisticated braking is driving important innovations for road safety.

Numerous ITS research activities have produced technical tools and guidelines for transportation department and transportation enterprises [12]. Regarding ITS research on tools, there are many activities that focused on simulation models to test and validate emergent solutions defined for road safety and traffic management. Three main categories of simulation models are then considered: 1) macroscopic models, 2) mesoscopic models and 3) microscopic models [9].

4. Impact of ITS requirements on communication technologies

4.1 First ITS programs and advances in communications

The automotive industry experienced major changes in the 1990s and this had a socio-economic impact. The number of vehicles reached 600 million in 1993. A large percentage of these vehicles are in America and Japan. One consequence of this increase results in traffic routes issues such as congestions, accidents and pollution. Traffic management is considered as promising solution to these problems. At the same time, telecommunication industries have experienced significant progress notably with the deployment of fiber optics. For instance, ARPA's High Speed Plastic Network (HSPN) program is based on the development of a plastic fiber optic network. This technology allows for faster and better transmissions than the technologies of the time and that use copper cables [13].

A key element of telecommunication innovative solutions is the deployment of advanced photonics and electronics to improve traffic and motorways in terms of traffic and road safety. Intelligent Vehicle and Intelligent Highway (IVHS) based programs are then developed in the three regions of the World due to these advances. In ITS developments, communications are put forward to provide solutions. From the earliest research and developments projects, the defined solutions were focused on intelligent resource management for optimal information dissemination [14].

Road safety is considered as one of the priorities of programs related to highways. The advances are based on the use of new radio communications, microwave, modern wired communications and traffic control systems based on communications. A large number of mobile units are authorized for emergency systems including police and fire departments. [14]. Weather alert systems, ordering of pickups and deliveries, and dispatch vehicles have occupied prime positions showing the need for new traffic management systems.

Communication systems for drivers are concerned with information on road markings, traffic conditions, guidance information, etc. Some programs have considered advanced systems to adapt highway speeds and maneuvers. Lightning components have also been defined to face problems related to obscure places.

A large number of ITS applications such as Automatic Vehicle Identification (AVI) and fleet management have been developed thanks to two-way communications between vehicles and infrastructures [15]. Thus, traffic management programs are more and more necessary to develop given the continuous increasing requirements. The concept of intelligent Vehicles and infrastructures that define IVHS (Intelligent Vehicle Highways Systems) represents a foundation of technologies developed in traffic management systems.

Regarding communication roles, technical barriers such as the occurrence of interference in communications have hampered the development of several traffic management solutions based on vehicular communications. The standardization of communications is seen as an important element for research solutions advancement and deployment.

HELP (Heavy Vehicle Electronic License Plate) is one of the first ITS programs based on communications. It aims to define an integrated management system combining vehicle-infrastructure communications. WIM (weigh in motion) as well as AVC (Automatic Vehicle Classification) allow the control and classification of some categories of vehicles are examples of HELP applications [15].

Most of HELP applications are directly dealing with communication characteristics such as the bit rates that reach up to 500,000 bits / sec. Integrated transponders are specified to allow two-way communications with capabilities to transmit large amounts of data. The capacities of road-side units communications must enable decoding of 8-line data simultaneously. Potential Warning for drivers have also been studied under this program. Examples include the use of sensors at frozen highways, overtaking periodic speed limits, and so on.

The electronic components are also used in the AVCS (Advanced Vehicle Control Systems) whose functions are used to control vehicles. The highlighted potential benefits of AVCS include substantial improvements in safety and major increases in road capacity. For the first AVCS application of CRCS, the road units would be installed next to road signs indicating the maximum speed. The speed limit is coded and transmitted to the driver.

Other developments on communications have concerned the algorithmic aspect for management functions. Examples include optimizing range and performance collisions minimization. Numerous algorithms for access control such as ALOHA and CSMA have been observed in studies of radio communications for ITS [16]. Several considered transmission strategies remain not acceptable for ITS applications requirements [16]. The behavior of short range mobile radios was one of the main issues. Communications technologies testing have considered road networks infrastructures such as highways with three unidirectional lines.

Following research and developments activities and definitions of new solutions, improvements have been made especially for strategies adaptations. However, required performances remains unmet. More research is thus still required to address specific ITS application requirements for optimization of road network management.

4.2 Communication technologies testing for ITS requirements

The period of ITS development between 1995 and 2005 is mainly marked by the phase of communication technologies real-life testing particularly at highways level. During this period, the number of daily accidents was enormous with an increasing number of vehicles. Although the construction of road networks to accommodate traffic growth is seen as a possible solution, geographical restrictions, narrow regions, steep terrain and social restrictions delineate the potential for growth in infrastructure.

In [17], RVC communications (road-vehicle communication), in addition to bidirectional communications from vehicles to infrastructures, from vehicles to vehicles are also required. Nevertheless, interference problems were still omnipresent due to transmitting with the same frequencies. Communication protocols and advanced technologies are thus required at low layers such as physical and medium access to minimize interference problems.

The Code Division Multiplexing (CDM) protocol was considered to modulate the signals transmitted between the mobile stations and the radio base stations of these communication systems [17] . A solution based on CDM enables the detection of multipath fading signals when a maximum rate is used. The multiplexing of the transmitted signals and the width of each parallel channel gives a powerful technique to deal with interference problems. More particularly, transmission errors are eliminated at maximum speeds of 4,0608 Mbps for vehicles with speeds up to 30 km /H. Also, using RoF (Radio over Fiber) systems for ITS represents an important contribution since it optimizes the vehicles messages reliability.

The standard MANET (Mobile Ad hoc Network) defined for mobile nodes has been considered for several ITS applications such as emergencies. Among MANET protocols, routing plays a major role to relay transmissions between mobile nodes. In [18], a test bed was developed for testing a MANET network for streets in a city. Defined scenarios for experiments are based on vehicle mobility patterns. The tested network can guarantee a throughput of 20k Bytes per second. Despite many other developments on MANET considered for streets, the results show many limitations, especially due to concentration density of signal fading.

Another communications concern for ITS applications relates to short-range transmission. Communication systems based on the technology G2 remained limited in relation to the needs of ITS applications. However, the G3 as well as packet mobile radio have brought some improvements [19]. Particularly, autonomous systems for fixed or mobile nodes that communicate in both directions exceeds the communications capabilities of the previous communication systems.

On the other hand, access control protocols such as CDMA (Code Division Multiple Access) and WCDMA (Wide Code Division Multiple Access) have also made improvements in vehicular traffic safety communications. Feasibility studies based on tests have stressed the importance of having capacities up to 64 Ghz.

The first period of ITS development as defined in this paper is recognized for various real-life tests on new communication technologies. Different transport network infrastructures have been considered. In Japan, the main tests were carried out in 2001 at the National Institute for Infrastructure Management [20]. They validated the concepts of "Smart Communication" techniques especially at highways for real-time information exchange. These tests represent an extension to the concepts of AHS (Automated Highway System) that began in the 1990s.

In addition to tests for traffic systems, other ones are considered for electronic toll collection systems (ETCs). Information is collected at the center and then broadcasted to the vehicles through radio broadcast, optical beacons and multiplexed FM [20]. DSRC (Dedicated Short-Range Communications) technology has been adopted by ETC applications.

Regarding research activities, this period of ITS evolution has been marked by large scale communications research activities. The objective is to provide support to various functional fields such as the availability of relevant information and the transmission of warning messages based on accurate information. Numerous solutions are based on the optimization of communication resources through different levels. At the physical level of the networks, the layers 1 and 2 are considered to minimize transmission errors and void collisions.) At higher levels such as the network layer, protocols are considered also for resource optimization.

The quality of data required must be assessed according to geographical standards, the completeness and accuracy of the position and the temporal and thematic accuracy. However, error rates in position accuracy were still non-solved during this period.

4.3 Role of Algorithms in ITS communications

4.3.1 Optimization solutions requirements for transportation communications

Numerous improvements have been made on the road network through the deployment of communications. Nevertheless, the performance limitations highlighted during the first period of ITS development as defined in this paper, have required more optimal solutions to achieve a better management of communications resources. Optimal dissemination of communications is one of the main objectives to be achieved. On the other hand, different optimization algorithms have been defined to face transportation network issues related to communications such as access collisions

Many emergent communications technologies such as RoF (Radio Over Fiber) [21] systems have been used. They enable communication optimizations through transmission errors minimization for more efficient vehicle transmissions reliability.

Solutions for communication optimization can be either at the low layers of the communications architectures (physical et medium access layers) or upper ones. While errors are minimized at low levels, more performance are achieved through upper levels such as network layer. Particularly, routing protocols play an important role in the transmission delays required by several ITS applications. Numerous recent research activities show promising new contributions for the effective functioning of vehicular communications due to their transmission performance.

4.3.2 Use of metaheuristics for ITS communications

The problem of routing in VANET networks represents a challenge du to numerous issues such as those related to mobility of the vehicles and the combinatorial complexity making the search of an optimal solution laborious. The routing protocol AOMDV (On Demand Multipath Distance Routing) is an example that shows combinatorial complexity from the problem formulation. Metaheuristics present problem-solving techniques with great potential regarding VANET networks issues. Several metaheuristics such as ant colonies are distinguished by their abilities to face problems related to VANET high mobility [22].

Ant colonies algorithms (ACO) are used with Dynamic Manet On Demand Routing Protocol (DYMO) to better manage the consequences of mobility and changes in the VANET environment. These algorithms are also used in the routing of VANET networks in order to cope with obstacles that affect the quality of transmissions between vehicles. Another category of metaheuristics such as PSO (Particle Swarm Optimization) is considered to solve routing problems of the AOMDV protocol. Genetic algorithms are also considered for VANET networks particularly for vehicles mobility modeling. A comparative analysis of the three metaheuristics is presented in [22] Where it is shown that algorithms based on ant colonies are more robust to face VANET networks challenges.

Despite metaheuristics contributions for VANET networks, there are still many challenges. Especially, the use of the bandwidth in VANET networks is still problematic. The density of vehicles in urban environments represents a constraint that is difficult to satisfy by considering only the metaheuristics for VANET routing. However, considering the contributions highlighted in the existing research activities on metaheuristics for VANET networks, maintaining these approaches for VANET routing solutions maximizes the quality of metrics required for VANET networks. Thus, hybrid algorithms seem to be promising for current and future ITS communications for vehicles.

5. Conclusion

The beginnings of intelligent transportation systems date back to the 1960s. These systems were motivated by socio-economic needs with particular attention to citizens mobility. With the increase in the number of vehicles, road safety concerns have emerged and has been considered in numerous government programs as well as research and development activities. ITS solutions are increasingly oriented to solve road safety problems as well as traffic management.

The review of ITS research themes presented in this paper shows continuous advances and evolutions of ITS technologies and techniques. More particularly, research and development solutions incorporating advanced technologies in communications for connected vehicles are considered as one of the main solutions that will optimize the deployment of recent ITS solutions for road safety.

Despite advances in communication technologies to make their resources more available, optimization requirements remain present and even increasing with the emergence of ITS safety applications. Recent research shows the importance of metaheuristics for ITS communications.

Research direction based on hybrid approaches integrating metaheuristics and emergent technologies seems to be promising for ITS safety applications solutions.

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