TEACHING MATERIAL GUIDANCE

1) Title of the material

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2) Which section of the SUMP it is relevant to?

This article is a conceptual contribution that discusses the integration of personal vehicles in smart city environments within Cooperative Intelligent Transport Systems (C-ITS). Therefore, the article can be linked to the third, fourth and fifth sections of the SUMP circle related respectively to the determination of planning framework, analysis of the mobility situation (in particular the analysis of problems and opportunities for all modes of transport - **subsection 3.2**.), scenario building and joint evaluation (development of scenarios of possible futures - **subsection 4.1**.) and vision and strategy development (arguments for stakeholders – **subsection 5.1**).

3) Which Mobility Manager knowledge this material is the most relevant to?

It is related to Transport and mobility planning (section 1 of the Mobility Manager competencies) especially 1b (employment of ITS/ICT and smart measures).

4) Problem approached and content overview

Problem approach – general understanding of the role of C-ITS and applying them to smart city environment. Cooperative Intelligent Transport Systems (C-ITS) have brought a technological revolution, especially for ground vehicles, in terms of road safety, traffic efficiency, and driver and passenger experience. So far, these advances have focused on traditional modes of transport, overlooking the new generation of personal vehicles that now flood our streets. Together with bicycles and motorbikes, personal mobility devices such as segways and electric scooters represent a robust, sustainable alternative that represents the future for achieving environmentally friendly personal mobility in urban environments. Soon, smart cities will become hyper-connected spaces where these vehicles should be integrated within the core C-ITS ecosystem. In this article, we provide a broad overview of the opportunities and challenges of this necessary integration, as well as the communication solutions that are already on the market to provide these mobile devices with low-cost and efficient connectivity. We also present a prototype on-board unit (OBU) with different communication options based on the Low Power Wide Area Network (LPWAN) paradigm and several sensors for collecting environmental information to facilitate eco-efficiency services. As suggested by the results obtained, this module allows the full integration of personal vehicles in smart city environments, demonstrating the capabilities of LoRaWAN and Narrow Band-Internet of Things (NB-IoT) communication technologies to provide vehicle connectivity and enabling mobile urban sensing.

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Fig. 1. Urban fully-connected vehicular scenario. White/red arrows: V2V/V2I links.

This article provides a broad overview of the opportunities and challenges presented by the new wave of eco-efficient vehicles. The specific needs of these items are discussed, as well as potential services that could be launched for this market segment. The role of these new 'moving things' in the urban sensor game and the use of big data is also explored, as drivers of sustainable mobility and environmental protection. What emerges from this discussion is the great momentum of personal mobility, especially in urban scenarios, and its potential for further development. However, it has also been noted that there is a lack of dedicated OBU solutions for this particular family of vehicles, to make them connected and intelligent. For this reason, a prototype OBU integrating a range of sensing devices and communication interfaces was presented and installed and tested onboard an electric scooter.

The results obtained during the validation tests demonstrated the effectiveness of the design. In addition, the performance of the two leading LPWAN technologies that were embedded in the prototype, namely LoRAWAN and Narrow Band-IoT (NB-IoT), was investigated, showing their different characteristics and how each is more suitable for certain types of services. Overall, the connectivity capabilities provided by the OBU

prototype enable the integration of sustainable vehicles in the coming era of C-ITS and smart cities. Furthermore, the paper provides an overview of recent work related to the personal vehicle ecosystem. An extensive discussion on the opportunities and challenges and communication technologies for personal vehicles has been provided. The proposed OBU prototype is also described and validation and performance results are analysed. At the end of the article, future research directions are identified.

5) Who could be interested in this material?

The article is aimed at students and those looking for inspiration in implementations in C-ITS in Smart Cities when such measures are applied in SUMP.

6) What is worth mentioning as an innovative factor for the reader?

An important set of challenges/gaps were observed that need to be addressed to provide eco-efficient personal vehicles with adequate connectivity:

- Lack of specific hardware/software designs for bicycles, scooters and similar vehicles.
- Efforts focus on cellular or IEEE 802.11 OCB technologies, but not on hybridisation of different communication technologies, adopting a Multi-Radio Access Technology (multi-RAT) approach.
- Connecting these vehicles to IPv6 networks, which is essential for their full integration into the Internet of the future, has not been addressed.
- The use of standard protocols has not been generalised, which is particularly important given the long-term life cycles of target vehicles.
- To the authors' knowledge, there is no work using LPWAN technologies to monitor, track and possibly notify vehicles.
- There are few proposals promoting transport intermodality and sustainable mobility options.
- Treating personal mobile devices as part of a future crowd-sensing ecosystem implies new IoV opportunities and sensory OBU platforms that are not currently present.

Urban mobility is currently experiencing great changes. As city dwellers become more aware of their carbon footprint, they are adopting more sustainable mobility options. Personal vehicles such as electric scooters, shared bikes, segways, etc. are populating our streets en masse. However, these elements are not yet part of C-ITS and smart city ecosystems. The results presented in this paper prove the validity of the proposal for the desired digitalization of this new wave of eco-efficient personal vehicles, given the communication capabilities provided by the developed OBUs, which also present significantly reduced energy consumption. The communication performance is evaluated depending on the LPWAN technology used, obtaining interesting results that indicate that the communication solution should be carefully selected depending on the characteristics of the application to be implemented. In future research, it is planned to extend the scope of work by evaluating network performance using additional communication

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technologies, e.g. 5G, integrating big data analytics and developing new services, such as fall detection or advanced vehicle diagnostics, to improve urban mobility and safety as well as environmental protection. Overall, mobile vehicle connectivity and mobile urban sensing open up a research niche that will be further explored in the coming years - from communication technologies to networking protocols and from power-constrained electronics integration to services using collected data. The potential benefits that can be expected from the deployment of these connected electric vehicles to reduce carbon emissions and improve citizens' quality of life are clear.

7) Limitations

The problem was analysed at a high level of generality, but specific solutions were also presented that could support integration processes within C-ITS. Nevertheless, the presented conclusions may serve as an inspiration for Polish cities regarding problems that may occur during the implementation of C-ITS solutions.

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