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Abstract

Environmental pressure and technological development is finally bringing Battery operated Electric Vehicles (BEVs) to the roads. Numerous studies have shown the energy-efficiency benefits of BEVs with respect to Internal Combustion Engine Vehicles (ICEVs). However, to the best of our knowledge, the impact of traffic management policies on energy efficiency when BEVs and ICEVs co-exist has not been addressed. In this paper, we evaluate the overall energy-efficiency of mixed BEVs-ICEVs scenarios in terms of total gasoline and electricity consumption for various penetration rates of BEVs at an isolated intersection. We employed our intelligent intersection management architecture (IIMA) equipped with the synchronous intersection management protocol (SIMP) against the conventional Round-Robin (RR) intersection management. Simulation results using the SUMO simulation framework show that SIMP outperforms RR for different penetration rates of BEVs, achieving up to ~200% upturn under particular traffic conditions.

Keywords: Intelligent Transportation System; Intersection Management; Electric Vehicles Penetration; Energy-Efficiency.

1. The Context and Motivation

Urban traffic management has the potential to improve overall safety and efficiency of urban transportation using intelligent intersection management protocols that not only alleviate traffic congestion but also improve fuel efficiency. On the other hand, BEVs can contribute to the achievement of sustainable transportation system, mainly due to zero exhaust emissions and higher motor efficiency Faria et al. (2012). Although numerous research studies have shown that the energy-efficiency benefits of BEVs against ICEVs, the corresponding evaluation of mixed BEVs-ICEVs scenarios has received considerably less attention, however, such a kind of analysis is relevant as BEVs and ICEVs should co-exist seamlessly before adopting BEVs on a large-scale. Therefore, innovative solutions that support the energy-efficient transition of mixed BEVs and ICEVs to fully BEVs scenarios are still needed. Hence, we focus on the energy-efficiency evaluation of mixed BEVs-ICEVs scenarios. In specific, we evaluate the overall gasoline and electricity consumption of our IIMA/SIMP Reddy et al. (2019) against a more traditional round-robin (RR) scheme.

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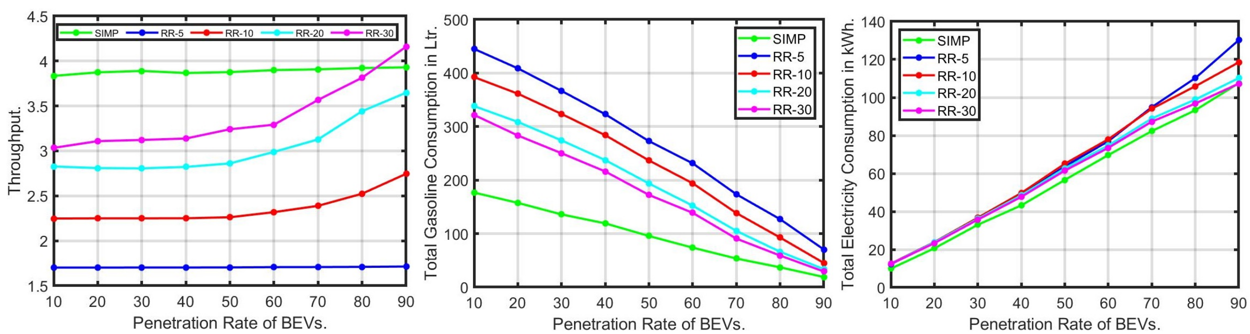
2. Synchronous Framework and Preliminary Results

The synchronous framework (IIMA/SIMP) was proposed to provide smoother access to mixed autonomous vehicles (AVs) and human-driven vehicles (HVs) at an isolated intersection. IIMA, essentially, discretizes the road lanes into a virtual grid of fixed-size cells while SIMP identifies HVs from AVs and synchronizes their directions at the intersection. Traffic lights decision-making relies on the Conflicting Directions Matrix (CDM) and on a given speed limit to ensure that only conflict-free access occurs. It also leverages AVs capabilities to seamlessly follow the protocol and traffic lights to serve HVs, which results in a step-wise incoming operation from multiple lanes. Conversely, RR favors the crossing of multiple consecutive vehicles but from one lane at a time.

In this work, we reinterpret the fundamental principles of SIMP/IIMA to evaluate the energy-efficiency of BEVs with different penetration rates co-existing with ICEVs. We employed the SUMO simulation framework v1.5.0 to test five intersection management strategies: IIMA/SIMP and RR-x (RR-5, RR-10, RR-20, RR-30) where x indicates the green time of 5, 10, 20, and 30 seconds; referred to in Fig. 1, followed by a 4s yellow phase. In each scenario, a 1000 mixed BEVs and ICEVs cross the intersection in the straight lane with 0.1Veh/s arrival rate randomly and uniformly injected from each direction. The penetration of BEVs starting from 10% until 90% has been analyzed where ICEVs percentage reduce accordingly. The rest of the simulation parameters are set as in Reddy et al. (2020).



(a) Intersection Throughput. (b) Gasoline Consumption (Ltr). (c) Electricity Consumption (kWh).

Fig. 1: Throughput, Gasoline and Electricity Consumption against Battery Electric Vehicles Penetration Rate.

The simulation results in Fig. 1b show that the expected reduction in fuel consumption due to BEVs penetration can be further improved up to ~200% when using SIMP instead of the more traditional RR-x. One reason is that vehicles have more idling time in RR-x than in SIMP. The equivalent analysis in terms of electricity consumption in Fig. 1c suggests that SIMP achieves overall better performance than RR-x under particular traffic conditions. This is explained by the regenerative braking of BEVs that restores the electricity consumed by the engine during the idling vehicle period. These preliminary but promising results are consistent with our double-goal direction of improving energy-efficiency of BEVs penetration while simultaneously offering better intersection throughput (as in Fig. 1a).

3. Conclusions

In this paper, we have analyzed the energy-efficiency performance of SIMP at different penetration rates of BEVs. Simulation results showed that SIMP outperforms the traditional RR scheme in terms of both the total gasoline and electricity consumption while improving intersection throughput. In the future, we aim to extend the analysis of the basic intersection scenarios to larger urban road networks that consider more complex/realistic traffic arrival patterns.

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