the electrodes – which are typically expected to last for at least five years in industrial processes before being replaced or refurbished. Such a long lifetime is very difficult to achieve for organic molecules, especially given that the electrode is exposed to chlorine and traces of oxygen at high temperatures. Further studies of the long-term stability of the organic catalyst are therefore now required. Nevertheless, by overturning the idea that organic catalysts are less effective than metals for electrochemistry, Yang and colleagues' study opens up a new strategy in the search for cheaper and more-energy-efficient industrial processes for making chlorine.

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Engineering

5G enables automated control of train traffic

Toktam Mahmoodi

Key tasks for ensuring railway safety have been performed automatically using fifth-generation (5G) mobile networks. The trial forms part of a Europe-wide scheme to test the feasibility of automating transport.

The ability to drive a car can be useful when travelling abroad, but it doesn't necessarily equip a driver with the knowledge required to navigate foreign roads and follow regulations. Autonomous vehicles suffer no such culture shock, and could make it easier to get around in a foreign country. The fifth generation of mobile networks (5G) provides the sort of connectivity and flexibility needed for safe autonomous driving. Writing in *IEEE Access*, Corujo *et al.*[1] put 5G to the test of managing the control signals used in railway operations – a step towards 5G-run automation in the broader transport sector.

Connected automated transport is a focus of European research investment, as is the role that 5G will have in realizing it (see go.nature.com/3hvnnnp). 5G networks hold promise because they can be tailored to provide specialized services for a given infrastructure. This is known as network slicing[2], and widespread use of this technique was not possible with previous generations of mobile networks. The 5G infrastructure is multiplexed, which means that each network 'slice' constitutes a potentially isolated network that can be customized for a particular task. Because of this, 5G can adjust its performance dynamically, depending on the application: for example, one task might need high bandwidth, rather than fast data transfer.

Researchers have started to test the capabilities of 5G for autonomous transportation – not only in terms of cars on roads[3], but also of public-transport vehicles, such as trains. As part of this initiative, the European Commission has established several cities as 'living labs', in which it has set up 5G networks in strategic areas, such as harbours. One such project is based in Aveiro, Portugal (see go.nature.com/41hjk), where Corujo *et al.* conducted their investigation of how 5G could be used to automate the operation of railway networks. The team examined two specific use cases: controlling the barriers at railway level crossings, and providing drivers (either human or algorithmic) with crucial safety information from the crossing as a train approaches it (Fig. 1).

In the first case, the authors used the 5G network to detect incoming trains automatically and to lower barriers to stop road traffic and pedestrians, with timing aligned with global regulations. The test was done on a railway track in Aveiro that is used infrequently and only by heavy freight trains. Corujo *et al.* placed sensors on the track a few kilometres from a level crossing. When these sensors detected an incoming train, the information was transmitted to a level-crossing controller that lowered the barriers to separate the road from the tracks.

The crucial safety decisions involved in this process required the reliable, fast communication provided by 5G. Conventional level crossings are controlled and monitored by various means, including manually by station staff, and automatically through sensors that are connected to the level-crossing controller

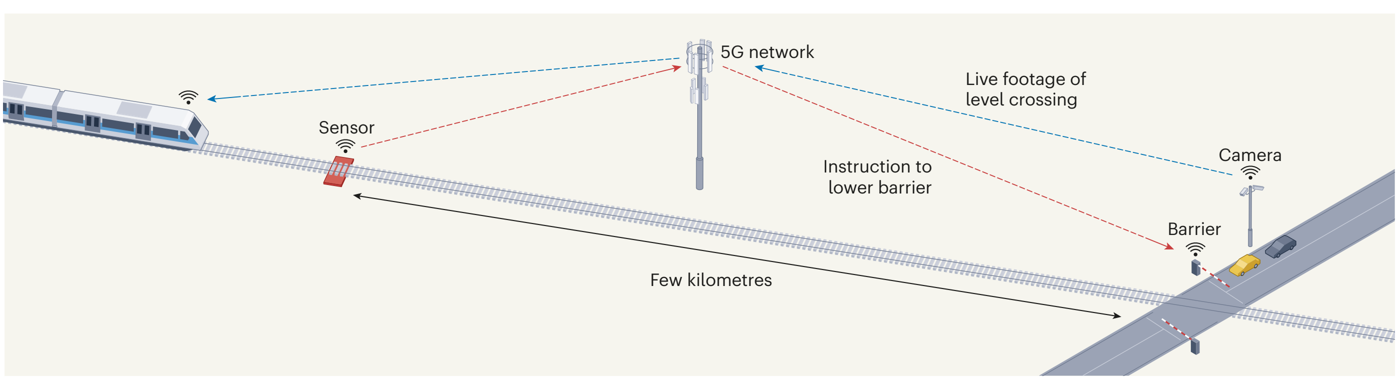

Figure 1 | Testing automation of a railway level crossing using 5G networks. Corujo *et al.*[1] tested two ways of using fifth-generation (5G) mobile networks to automate control of a level crossing on a train track in Aveiro, Portugal. In the first test, the authors detected a train using track sensors located a few kilometres from the level crossing, and transmitted the information (red arrows) to a level-crossing controller that then lowered the barriers, preventing road traffic from crossing the track. In the second test, live video footage of a level crossing was transmitted (blue arrows) to the driver as the train approached the crossing. The 5G network provided the speed and bandwidth necessary for safe automation in preliminary tests conducted in a controlled laboratory environment, and showed potential for similar success in the real-world setting.

by cable. Wireless connections, such as 5G, offer fast and reliable connectivity without the maintenance required for cable-based signalling.

The second test was designed to assess whether transmission of live video footage from the level crossing could improve conductors' decision-making as the train approached the crossing. Using this information, a human driver or an automated engine could assess the state of the level crossing before reaching it, and make a safe stop if necessary. Although this is not as time-sensitive as the first test, live (and real-time) video transmission requires substantial bandwidth, which is not provided by the radio communication systems that are currently used by railway operations.

The authors used key metrics to establish the success of each test. Their first use case required low latency, which is the time it takes for data to pass from one point on a network to another; low jitter, which is the variation in the amount of latency; and relatively low packet loss, which is a measure of data loss during transmission. The second use case needed high bandwidth, low packet loss and relatively low latency. Corujo *et al.* conducted both tests first in a controlled laboratory environment, and then in the Aveiro living lab, using two 5G networks. The networks achieved the minimal performance requirements for all four metrics in the standard lab setting, but packet loss was a problem at high transmission rates in the living lab. One of the networks also failed to achieve the required latency and jitter, but the other succeeded.

The test environment has a key role in ensuring the success of such trials. Standard labs offer controlled conditions that aid the reproducibility of results, but these conditions can be unrealistic and therefore ultimately unhelpful. By contrast, on-site tests are more informative, but can involve certain real-world challenges. For example, when it comes to wireless communication, coverage is always a major obstacle, and test environments that are not fully controlled must overcome this problem.

Corujo *et al.* used existing technology to improve the coverage by better distributing the part of a mobile telecommunication system known as the radio access network. The set-up that they used is typically referred to as a cloud radio access network or a decomposed radio access network. In this approach, the processor undertaking heavy computation is located centrally, close to the power supply, and is separated from the radio transmission unit, so that this unit can be placed close to the user[4]. Aside from improving distribution, this set-up has numerous advantages, including low communication latency (through proximity to the user) and improved coordination of radio resources — all contributing to performance enhancements.

The authors' results show that connected railway operation can be automated with a 5G network in a controlled environment. The tests performed in the Aveiro living lab were not as successful as those in the standard lab, but they still show 5G's tremendous potential for delivering automated railway services. Corujo and colleagues' experiments also pave the way for exploration of how 5G could automate other types of transport, including air or sea transportation. These cases would require greater network coverage and more diverse radio technologies, as well as integration of several wireless communication systems. However, the approach adopted by Corujo *et al.* could assist in these endeavours.

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