**EIT Digital Doctoral School– Industrial PhD position proposal**

# Exploiting the Location information for Adaptive Beamforming in Transport Systems

Partners Information

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| Industrial partner | Telefónica UK Limited |
| Industrial Advisor | |

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| Academic/research partner | University of Glasgow |
| Does the academic partner grant the PhD Degree? | YES |

PhD project information

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| PhD Thesis – Title | Exploiting the Location information for Adaptive Beamforming in Transport Systems |
| PhD Thesis – Summary | The transport sector is a major driver of economies across the globe, and its market is estimated at £5 trillion. Lately, the digital augmentation of the sector has helped in creating new businesses, and revenue streams which currently contribute approximately £275 billion to economies worldwide. Further growth of the so-called intelligent transport systems is contingent on the synergy with the wireless telecommunication networks that provide the resources for fast, reliable and robust connectivity.<br><br>Millimetre-wave (mm-wave) communication is a wireless technology with massive potential and can support ultra-fast and high data-rates that are significantly higher than the conventional microwave frequency mobile networks. However, there are several physical and engineering challenges that currently limit a widescale deployment of mm-wave networks. One of them is the moving vehicle, for which several precursory measures need to be taken to establish a reliable communication link. These pre-configuration overheads not only make the overall communication system inefficient in terms of time but energy expenditure as well.<br><br>Here we propose a self-organising mobile communication system that is,<br>a. Capable of inferring the mobility patterns of the transport vehicles running on roadside and railway infrastructures, and then can<br>b. Reconfigure itself for optimal quality of service; and<br>c. Equipped with adaptive antenna structures that enable fast beamforming with minimal latency.<br>The proposed system can significantly reduce the initial overhead required to establish a connection by utilizing the on-hand contextual information extracted from the location. Moreover, it can |

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| | help reduce the energy footprint of mobile communication networks especially for transportation systems, and in turn, provide seamless connectivity to mobile users utilising public transport.<br><br>The PhD will involve the development of location-assisted beamforming techniques and realized through adaptive antenna array structures. The project will also use technologies such as machine learning to develop predictive models from the contextual information of the location.<br><br>The novelty of the project lies in exploiting the location information of moving vehicles to reconfigure the mobile network as needed. The proposed project completely aligns with the research directions of the industrial partner, Telefónica UK Limited, which is actively working with public transport infrastructure entities in the UK such as TfL and Network Rail to develop 5G-enabled ITS. Telefónica also has a global product offering in the management of fleet vehicles using the internet of things (IoT) technology. |
| No. of PhD positions – maximum 2 (if 2 positions, then please differentiate them) | 1 |
| PhD duration | 3,5 |
| Innovation Focus Area: | Digital Cities, Digital Tech |

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| DTC location | Edinburgh |

PhD thesis motivation and innovation valorisation

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| Rationale/challenge | Despite the many attractive properties of millimetre-wave (mm-wave) communications chief among them the high bandwidth, the underlying physics of electromagnetic waves at mm-wave frequencies substantially increase the communication channel pathloss and absorption. To overcome these propagation constraints, new hardware systems and architecture frameworks such as large-scale antenna array systems must be used, which are empowered with a computationally-intensive process of adaptive beamforming. However, at mm-wave frequencies the cost of beamforming becomes prohibitively high, owing to the increased hardware complexity that arises due to many antennas, exhaustive beam training required, and the subsequent excessive power consumption of these systems. Therefore, a major challenge in the realization of mm-wave communications is to reduce the beam-training overhead. In the public transport sector such as buses, trams and trains, all the vehicles operate at fixed routes and schedules, and therefore, through this prior, contextual information, the location of vehicles can be predicted with high accuracy at any given time. It has been shown that this knowledge about the transport infrastructure can be used to reduce the time and space complexity of the beam-training overhead required for establishing communication links [1], [2]. Furthermore, self-organization of |

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| | mobile networks at higher frequencies like the mm-wave plays an integral role when it comes to providing the required quality-of-service [3]. To do so, a flexible, adaptive and online capability [4] to infer the mobility patterns of the transport system needs to be developed.<br><br>[1] N. Garcia, H. Wymeersch, E. G. Strom, and D. Slock, 'Location-aided mm-wave channel estimation for vehicular communication', in *2016 IEEE 17th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Edinburgh, Jul. 2016, pp. 1–5, doi: 10.1109/SPAWC.2016.7536855.<br>[2] F. Maschietti, D. Gesbert, P. de Kerret, and H. Wymeersch, 'Robust Location-Aided Beam Alignment in Millimeter Wave Massive MIMO', in *GLOBECOM 2017 - 2017 IEEE Global Communications Conference*, Singapore, Dec. 2017, pp. 1–6, doi: 10.1109/GLOCOM.2017.8254901.<br>[3] R. Amiri and H. Mehrpouyan, 'Self-Organizing mm Wave Networks: A Power Allocation Scheme Based on Machine Learning', in *2018 11th Global Symposium on Millimeter Waves (GSMM)*, Boulder, CO, USA, May 2018, pp. 1–4, doi: 10.1109/GSMM.2018.8439323.<br>[4] V. Va, T. Shimizu, G. Bansal, and R. W. Heath, 'Online Learning for Position-Aided Millimeter Wave Beam Training', *IEEE Access*, vol. 7, pp. 30507–30526, 2019, doi: 10.1109/ACCESS.2019.2902372. |
| Innovation | The overarching aim and innovation of this project are to leverage the prior, on-hand location information of vehicles, learned in part from the routes and schedules, and develop a self-organizing mobile network architecture that optimizes the radio link-budget. The inherent challenges of the mm-wave communication network will be addressed through a resilient beamforming strategy that can be reconfigured based on the geospatial information from the vehicles which is partly inferred from the transport infrastructure.<br><br>The project will also develop novel, machine learning-based, real-time direction estimation algorithms through which the antenna beam patterns can be efficiently coordinated and aligned in the required directions to provide maximal signal strengths at the receiver end of the communication system. |
| Expected academic - outcomes | It is expected that at least 2 journal articles, 2 conference papers and a PhD thesis will come out of the work done in this project. |
| Concrete innovations expected as the outcome of the proposal - | The outcomes of the project will primarily consist of a self-organising network (SON) scheme for an intelligent transport system (ITS) that leverages the location information of vehicles in configuring the network parameters, which is realised through adaptive beamforming of the radio links. The new technologies developed in the project will result in patent(s) applied through the support of the business and innovation office at the University of Glasgow, and the industrial partner, Telefónica UK Limited.<br><br>It is expected that the proposed location-aware beamforming service will improve Telefónica's portfolio of Smart Steps Platform, |

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| | specifically targeted for public transport systems. The main innovation of the project lies in learning the mobility patterns of the transport vehicle from the network data, which will be accordingly be used to reconfigure the network resources in real-time. To realise this, mobile events from the $O_2$ network will be required, which will be provided by the $O_2$ motion lab.<br><br>Under the $O_2$ motion and Smart Steps platforms, Telefónica already has an established data-driven customer analytics product, that enables business organisations to access mobile user extracted dynamic insights, which can then be used to make business decisions. However, until now these insights have been gathered from individual mobile users. This project will explore the patterns of users as a group, and these patterns will then be used to make real-time decisions to reconfigure the mobile network resources.<br><br>To further test the concept in a physical environment, we will seek the transfer of knowledge to create a spin-off for which we will seek support from the Telefónica's open innovation hub, Wayra UK in the Intelligent Mobility Accelerator program, that only provides Telefónica's network resources but business development support as well. |
| Expected impact of the PhD outcomes with respect to business– | Data-rich, mobile user analytics solutions have already proven to be a huge success in gauging customer behaviour and marketing trends. However, such solutions often involve huge risks as decisions are primarily taken from the data collected in the past. The current global pandemic event has disrupted every aspect of our lives today. There is now an ever-greater need to develop analytics-based solutions through which decisions can be made based on real-time events. The work done in this project directly falls under the business and research directions of the industrial partner, Telefónica UK Limited, especially, the O2 motion lab which works in exploiting the mobile user location data to identify customer behaviour and generate marketing insights. This project will contribute to the business line of Telefónica in two ways:<br>a. Enable real-time decisions for network reconfiguration,<br>b. Expand Telefónica's portfolio in the ITS.<br><br>The academic and industrial partners have experience of collaborating in the past on the development of SONs. In this project, a particular focus will be realising a SON use-case in smart transportation. Moreover, the location-aware adaptive beamforming will provide an edge over network operators by making the network maintenance and operation more energy efficient with reduced human interventions.<br><br>Beyond the anticipated applications in enhanced infotainment services in transport systems, the project will, more importantly, help in realising a greener mobile communication network through optimal use of energy resources, enabled by the self-organisation capabilities of the proposed network. Moreover, other potential applications lie in the improved safety of transport vehicles, |

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| | intelligent traffic management and flow, and improvement of commutes in terms of time. |

PhD thesis timeline and milestones

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| Deadlines/milestones | ▪ Develop a space-time, mm-wave propagation channel model with multiple dominant paths<br>▪ Develop the machine learning framework for location beamforming exploiting the Smart Steps data, which is the mobile user data captured by the O2 (Telefónica) networks across the UK.<br>▪ Develop the prototype to collect location information from roadside infrastructure; Prepare 1 journal paper and 1 conference paper<br>▪ Develop the antenna array design and machine learning framework for location-aware beamforming<br>▪ Perform the validation of the location-assisted beamforming system, thesis preparation and 1 journal manuscript preparation. |

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| International mobility plan. (Possible countries/ institutions to attend and or work from) | Transport for London, United Kingdom<br>Network Rail, United Kingdom |
| Will the PhD Student do the Business Development Experience at Industrial Partner premises? | Yes |