

THE SUITABILITY OF A MOBILE COMMUNICATIONS NETWORK TO DELIVER HIGH-RESOLUTION AIR QUALITY MEASUREMENTS



In most countries, mobile network operators (MNOs) deploy tens of thousands of base stations to deliver mobile communications services to their customers. It is estimated that there are approximately 7 million base stations worldwide [1]. These deployments positively correlate with population density and base stations come in many different types from large rural masts, approx. 20-25 metres high, to street works locations which are typically around 10-15 metres high, to rooftop sites, whose height depend on the height of the building that hosts the equipment.

In addition to providing wireless connectivity to subscribers, a mobile communications network (MCN) can also become a powerful environmental sensor thanks to the following key characteristics: 1) its pervasive infrastructure can be used as real estate for hosting a wide range of sensors in a cost-effective manner (weather, air quality, noise, etc.) 2) its ability to capture subscriber mobility patterns in aggregated and anonymised form in compliance with General Data Protection Regulation (GDPR) 3) its intrinsic ability to detect humidity and rain at certain frequencies, given the physical properties of the wireless channel.

By strategically leveraging these benefits, an MNO can deliver a high-resolution and real-time environmental data set that can enrich and add resolution to existing sources of data and be used for a wide variety of use cases, for example: to increase accuracy and resolution of weather forecasting and nowcasting models, to calculate accurate risk factors for wildfire and floods and understand their impact on communities as they occur, to build high-resolution air quality (AQ) maps that can inform policy makers on the most effective pollution mitigation strategies.

We refer to this concept as "Network as a Sensor".

Vodafone is already unlocking the power of its mobility patterns through its Vodafone Analytics practice [2] and, together with Vantage Towers and its ecosystem of partners, is running several pilots across Europe to prove how telecommunications infrastructure can deliver high-resolution and real-time data assets on weather [3].

This paper focusses on a pilot on AQ in the UK, where Vodafone is working in partnership with Vantage Towers, Cornerstone, Wireless DNA, Scotswolds, Cambridge University, and Cambridge Environmental Research Consultants (CERC). The pilot is live in the city of Glasgow, where a network of AQ sensors is being deployed on a selection of base stations in the city centre to monitor AQ at high resolution in space and time. The data derived from the sensors can be used in harmony with mathematical

modelling to build high-resolution AQ maps and accurate forecasts and identify local sources of air pollution versus the regional background.

Initial findings suggest that:

- Existing base stations are suitable for hosting AQ sensors, and there is no detectable detrimental effect of electromagnetic radiation on the sensor behaviour
- The accuracy of the chosen sensors agrees well with Reference methods
- Most base stations are in ideal locations for the assessment of AQ exposure

While this article is being written, the project is entering its second phase of execution, with the key objective of assimilating sensor data into CERC's Atmospheric Dispersion Modelling System (ADMS-Urban) [4, 5, 6] in order to constrain emission inventories which can then provide key information for policy decisions on the local and regional scale, and which can produce high spatial resolution maps for public dissemination, including AQ forecasts.

Network as a Sensor for Air Quality Mitigation and Management

As conventional monitoring networks often lack spatial granularity and are typically sparse and fragmented across countries, an MCN can overcome these limitations by enabling measurements of AQ at high granularity in space and time and provide broad spatial coverage with a consistent performance across country borders. Moreover, the presence of an MCN correlates with population density, which makes its spatial distribution ideal for better understanding the impacts of pollution hot spots on communities.

The data generated by such a network has the potential to be transformative as it can truly drive strategic change and mitigation actions.

This high spatial and temporal resolution data can in fact empower stakeholders to achieve the following, at scale:

- Measure air pollution for action and mitigation, in addition to compliance with standards and guidelines, by truly understanding pollution spikes at different times of the day in different locations of a given area
- Understand those emissions which are generated locally, and those that are imported from elsewhere due to long-range transport
- Accurately calculate local emission indices, revealing the amount of pollutant produced per unit of carbon-based fuels combusted

In the future, it will also be possible to use CO₂ measurements in their own right as part of carbon footprint studies.

The intended outcome of this study is to demonstrate how this pilot can potentially be scaled to provide a "data as a service" platform across Vodafone's entire global operation and beyond, underpinned by the following:

- Cost-effective deployment of compact AQ sensors attached to mobile communications infrastructure in key strategic locations, as illustrated in Figure 1, measuring a range of key airborne pollutants at 1-minute resolution. This deployment strategy not only enables easy access to available real estate, power, and data connectivity, but also ensures a consistent and long-term approach in maintaining these sensors calibrated and fit for purpose by leveraging the standard site maintenance procedures adopted by MNOs.
- Standardised cloud-based methodology to deploy, maintain, calibrate sensors against reference measurements, and automatically perform quality control and quality assurance (QA/QC).
- AQ model that ingests measurement data, amongst a variety of other data sources, and produces high resolution pollution maps and prediction of pollution patterns with improved accuracy
- Additional source apportionment outputs obtained by separating local vs regional emissions to allow better targeting of intervention policies
- A dashboard and visualisation system to allow users to access AQ data or AQ maps in near real time



Figure 1: Illustration of a compact AQ monitor attached to a base station

Network as a Sensor pilot in Glasgow

Scotland has some of the most stringent AQ standards to be found anywhere in the world and has recently introduced a wide range of measures under Clean Air for Scotland 2 (CAFS2) aimed at further improving AQ across the country.

Glasgow is the first Scottish city to implement a Low Emission Zone (LEZ) restricting vehicles older than Euro 4 as from June 1st 2023 and imposing fines for non-compliant vehicles. This project coincides with the introduction of the LEZ and has the potential to contribute to the understanding of how the LEZ can improve AQ in the city centre over this period. All other major Scottish cities are also implementing LEZ's during 2024.

The AQ pilot in Glasgow, Scotland, is organised into two key phases:

Phase 1 (June 2022 – Present): This first phase is designed to test a range of different AQ sensor systems from a number of manufacturers attached to a major cellular transmitter in a central location in the city of Glasgow. At this location, the large array of AQ sensors is exposed to well mixed air volumes allowing direct comparisons of sensor performance during Phase 1, as shown in Figure 2. The sensors are measuring NO, NO₂, O₃, CO₂, PM₁₀, PM_{2.5} at 1-minute intervals. Reference AQ data is available from a nearby conventional monitoring station operated by the city and this is enhanced by an additional reference-grade CO₂ instrument made available to the project by Cambridge University. Data is collected via the manufacturer's online user interfaces and API services by Wireless DNA and made available for analysis by our partners from Cambridge University. A schematic of the end-to-end architecture is illustrated in Figure 3.

Outcome of Phase 1

Initial results show that proximity to a transmission tower has no discernible effect on the data quality (Figure 4). The out-of-box measurements from the sensor systems broadly track the nearby reference observations from Glasgow Townhead station (Pearson's coefficient $r > 0.8$ except for the CO₂ and one of the PM_{2.5} of Platform 2) and the unique diurnal patterns in the cellular transmission data are not observed in any of the sensor readings. Some candidates performed better than others and as a result those were chosen to feature in Phase 2 of the project.



Figure 2: Phase 1 test site: rooftop base station in central Glasgow, with a large array of AQ sensor attached to it

Phase 2 (June 2023 – Dec 2023): The second phase of the project has the objective of deploying a small network of devices across Glasgow and across a chosen city in Spain, whilst still operating the Phase 1 site as an additional node within the network and as a facility allowing the sensor manufacturers to provide updated test equipment for emerging sensing technologies. Figure 5 illustrates the end-to-end system diagram, whereas Figure 6 illustrates the type of high spatial resolution AQ data that Phase 2 will deliver.

The key objectives of Phase 2 are as follows:

- Demonstrate that the location of the cellular sites is compatible with AQ objectives in the test city and show the ease of installation on a variety of cellular site types
- Comparison of sensor data with that from existing reference grade monitors operated by the cities to demonstrate accuracy and reliability. As part of this, two different sensor types will be co-located at two reference sites in each city.
- Demonstration of the comparability of a network of at least 10 identical sensor systems over a period of at least six months demonstrating stability and proving our QA/QC measures

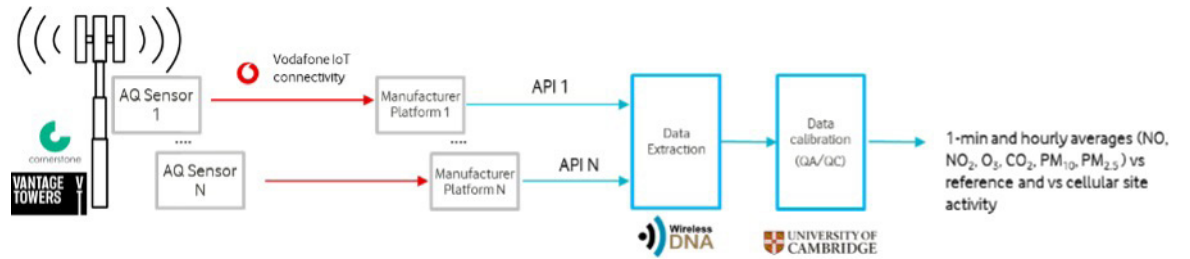


Figure 3: Phase 1 end-to-end system diagram: AQ sensors are colocated on the same site in central Glasgow

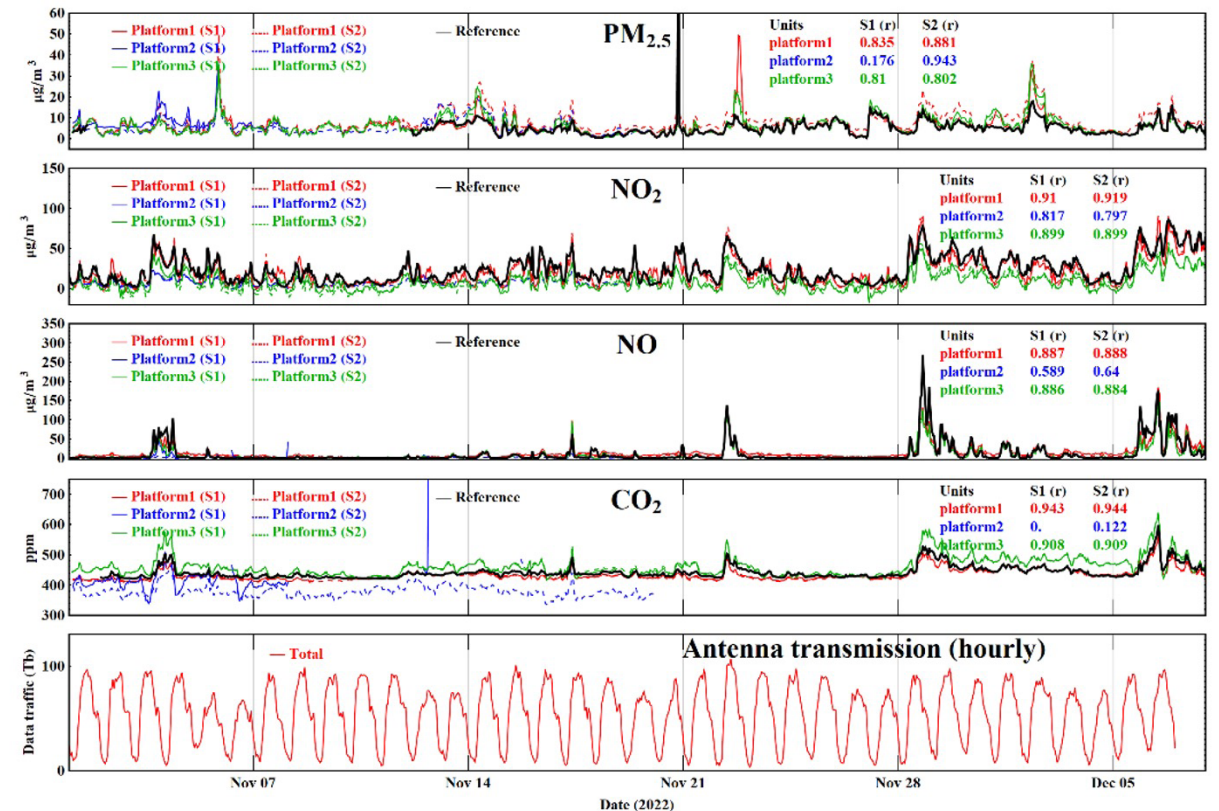


Figure 4: Hourly average observations and network transmission data from 1 November to 7 December 2022 for co-located pairs of sensors nodes from three manufactures showing CO₂ and AQ species including PM_{2.5}, NO and NO₂. Reference AQ data is from Glasgow Townhead urban background station while the CO₂ is from a reference grade Licor instrument deployed for this study. Sensor data are out-of-box readings as provided by each manufacturer.

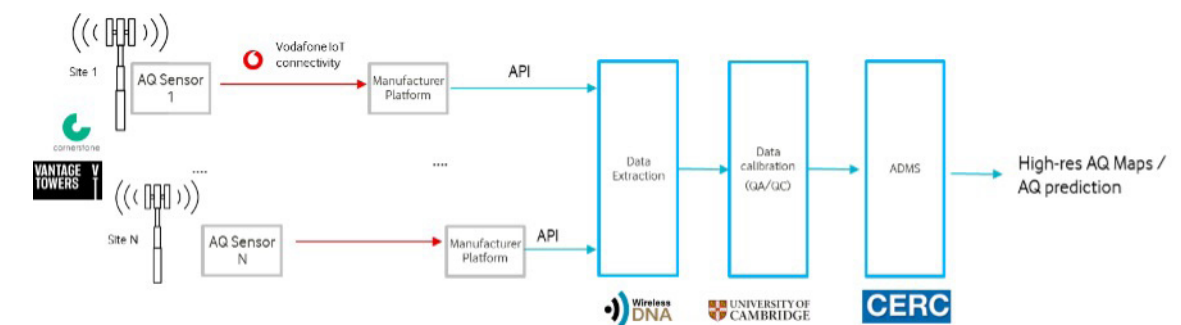


Figure 5 Phase 2 end-to-end system diagram: AQ sensors are installed on a number of sites in the city centre of Glasgow

- Assimilation of monitoring data within a sophisticated AQ model (ADMS-Urban) in conjunction with CERC to further enhance the spatial coverage of the monitoring network by using the model to interpolate between test locations (10 metre grid squares) and use the emissions indices generated by the monitoring data to improve local emissions inventories used by the model. The model also provides the ability to predict local AQ up to three days in advance and can provide likely outcomes of "what if" scenarios providing essential input to control and mitigation strategies.
- Develop the sensor platforms in conjunction with manufacturers to optimise the performance of the sensor systems, reduce cost and scale the production of an "ideal" version of these technologies to be used at a commercial scale.
- Improve the data collection processes in conjunction with sensor manufacturers such that they can be successfully scaled for commercialisation. Automate device geo-mapping QA/QC, and validation processes which are being manually applied during Phase 1, to further reduce operational costs and provide near real time validation of data to be disseminated to clients.
- Advance the development of reporting and visualisation tools

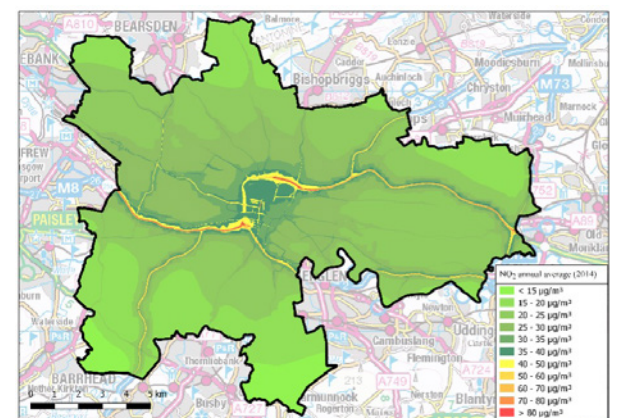


Figure 6: Map of Glasgow modelled annual average NO₂ concentration for 2014, produced using ADMS-Urban for a previous project called QCumber-EnvHealth [7], which brought together CERC and the Universities of Edinburgh, Glasgow and Strathclyde with Transport Scotland. This map demonstrates the type of high spatial resolution AQ data that Phase 2 will deliver. Contains OS OpenData imagery © Crown copyright 2015.

Conclusion

The significant advances made in small sensor technology in recent years is such that the capital cost of such devices is significantly lower than that of conventional AQ monitoring systems and they can be deployed in many locations where conventional monitors cannot. However, the operational costs of running a network of sensor systems can still be significant, let alone the task of finding suitable monitoring locations with planning consent, power, communications and security. This is where leveraging an existing network infrastructure such as a cellular network can enable easy and sustainable deployment and reduce operational costs.

Phase 1 of the AQ pilot in Glasgow has demonstrated that mobile networks are suitable for hosting AQ sensors and that, thanks to their pervasive infrastructure, they are well positioned to cost-effectively scale hyper-local AQ monitoring networks. The next phases of the project will illustrate how such monitoring networks can work in harmony with mathematical models to produce accurate and high-resolution AQ maps, and empower stakeholders to target mitigation and policy interventions, to help improve AQ for all.

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