Environmental Monitoring

A Guide to Ensuring a Successful Mobile IoT Deployment

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The GSMA represents the interests of mobile operators worldwide, uniting nearly 800 operators with more than 300 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors. The GSMA also produces industry-leading events such as Mobile World Congress, Mobile World Congress Shanghai, Mobile World Congress Americas and the Mobile 360 Series of conferences.

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Environmental monitoring using sensors connected by Mobile IoT is one of the best tools a city has to address pollution and climate change issues. This guide explains how a city or environmental organisation can best approach an IoT environmental monitoring project and what steps they need to take to ensure success.

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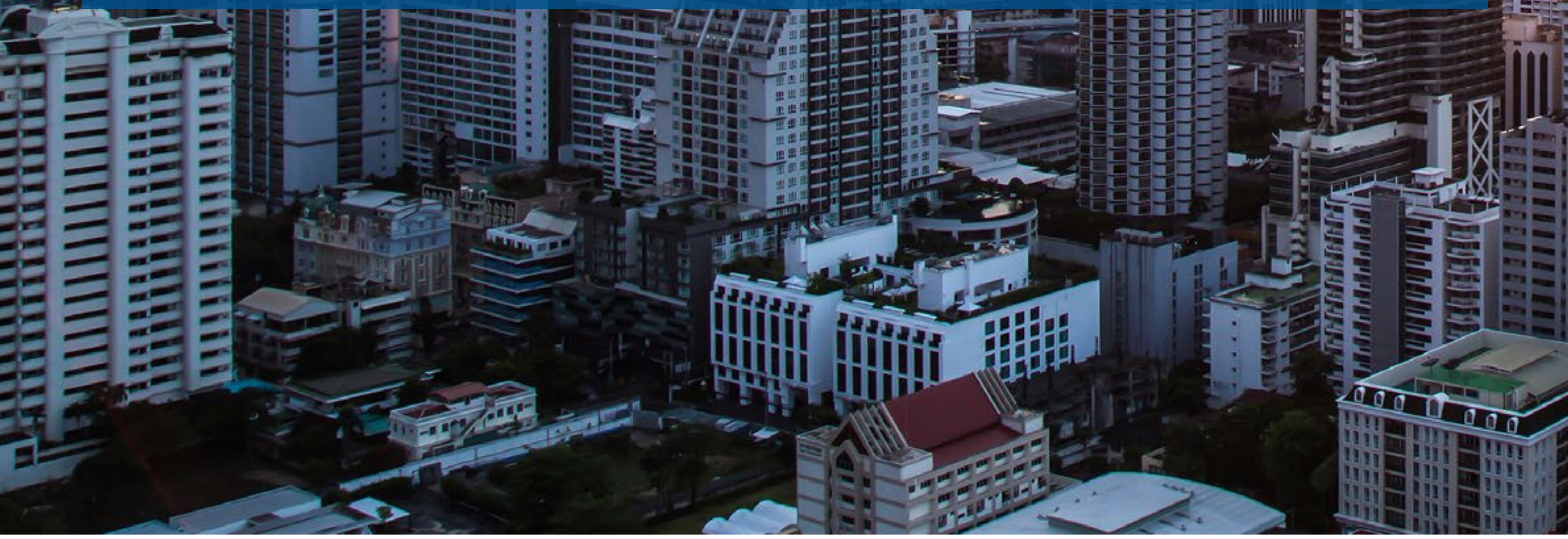
Introduction

Environmental monitoring and management is becoming more important, as managing the environment and understanding its impacts drives increasing amounts of regulation and activities to reduce pollution. IoT sensors are able to give accurate real-time data on the environment around us to help us understand how we affect the environment and take actions to improve quality of life in cities.

Environmental sensors have reduced in in size and cost. They are now readily available and can be installed at many points across a city where it would have been impractical to do so just a few years ago. Mobile technology has also advanced to provide a robust connectivity solution, Mobile IoT, that enables these sensors to be deployed efficiently and effectively by city authorities and other bodies. Mobile IoT technologies are Low Power Wide Area networks from mobile operators, including NB-IoT and LTE-M.

Cities can measure many parameters as part of an environmental monitoring deployment that utilises connected IoT sensors, including air and water quality, weather, noise, pollen, smoke and other attributes that may affect quality of life in a city including those related to disaster management, such as seismic and flood sensors.

Improving air quality is particularly important to many cities, with gaseous and particulate emissions from vehicles and industry leading to chronic health problems for many, and shortening the life span of thousands of people in urban areas. In order to control these emissions, the city first needs to know both where the pollution hotspots are and how the pollution is generated. With this information, cities can plan for cleaner air by incentivising the drivers of polluting vehicles to stay away or changing road layouts to direct traffic away from sensitive areas.



Cities planning to deploy IoT based environmental monitoring to investigate, and potentially improve, environmental parameters such as air quality, need to bear in mind a number of criteria that will optimise their deployments. By planning around these criteria, cities will be able to deploy sensors in appropriate locations in order to get appropriate results to act upon.

- **Data accuracy.** The accuracy of environmental monitoring will depend on a number of factors. For example, the higher quality the silicon in the sensor, the more precise readings will be, with a smaller margin of error. Environmental sensors work by identifying tiny changes in current caused by reaction with specific molecules. The more robust the circuitry to identify these changes, the more accurate the results, and the lower the minimum detection limit will be. However better quality increases cost. Therefore, cities need to decide how to best balance the accuracy of environmental monitoring by understanding what the data will be used for, against the cost.
- **Sensor location.** This refers to making sure that the sensors are located in the correct position, and measuring the right attributes. As sensors have reduced in size, it is possible to place them in many more locations, and even have them on moving vehicles.
- **Local environmental conditions.** Readings from environmental monitoring stations are extremely sensitive to changes in temperature and humidity amongst other factors. A hot day may result in different readings than a cold day. Therefore they need to be tested and any variation in readings recognised through data analytics.
- **Match with city planning.** Cities need to ensure that the environmental monitoring tools they deploy are suitable for meeting the cities objectives. Low cost sensors may not be suitable for collecting valuable data such as in disaster management. Where a city needs to solve environmental issues, not just measure them, then integration of different IoT services such as Licence Plate Readers and CCTV should be explored.

Mobile operators are well placed to implement environmental monitoring solutions at scale across a city, and provide the analytics needed to create value from the raw data. Newly developed Low Power Wide Area (LPWA) networks, also known as Mobile IoT networks, are designed specifically to support environmental IoT sensors. These networks are designed to be secure, scalable, future-proofed and operate cost-effectively.

GSMA, working with the Royal Borough of Greenwich, have developed an air quality proof of concept to demonstrate how IoT and Big Data Analytics can assist in understanding air pollution for the benefit of Greenwich residents, commuters and visitors. Further information can be found at **www.gsma.com/smartlondon**

As part of GSMA's work with the Royal Borough of Greenwich, the Smogmobile was deployed to act as a proxy for a large range of air quality sensors and travel around the Borough. The results from the Smogmobile illustrate the types of insights that may be obtained from the deployment of large numbers of IoT air quality sensors as they move around the city, for example on council vehicles.

The environmental monitoring value chain

Before investigating and building a network of environmental monitoring stations, it helps to understand the environmental monitoring value chain, the stakeholders and attributes within it and the needs of any new technology driven solution.

ENVIRONMENTAL MONITORING VALUE CHAIN

City and Regulator	Environmental Partners	Internet of Things	Analytics and Insight
Cities and Regulators	Universities	Sensors and communications	Intergrating data sets
Local needs	Environmental agencies	Installation	Data analysis
Community	Healthcare providers	IoT platform	Actioning insight

CITIES AND REGULATORS

Increasingly, regulation is driving the need to deploy many environmental monitoring services, such as for air and water quality measurement. Many governments are setting targets on a national level that local areas and cities need to comply with. In some instances, it's possible for a city to be fined if they do not meet standards set down by national governments and regulators.

As important as national regulations are, local concerns also drive the need for environmental monitoring, and it is often only local teams of people that understand the environmental impacts that need to be monitored. Regulations, whether local or national can be met by connected IoT devices providing data that shows current status, and any improvement over time. Data generated by these devices is critical to show regulatory compliance in a consistent way that can be interpreted by both local and national regulators.

Local groups and residents can be a powerful force is highlighting concerns about high levels of pollution or environmental damage that may need to be addressed. Flexibility in the deployment of environmental monitoring stations is key to support these groups, with some sensors deployed into certain locations for limited times to backup data from other services. For example, temporarily deployed traffic counters or cameras can be used to backup data from certain areas of the city and provide a more comprehensive suite of information for dealing with hyperlocal issues.

ENVIRONMENTAL PARTNERS

Environmental monitoring can be driven by a number of organisations in partnership with each other. Although the city is often the place with the most acute pollution that needs monitoring and resolving, research institutes and environmental groups play an important role in ensuring that any activities the city undertakes offer meaningful and accurate results. Many organisations hold important expertise and data that can help the city drive towards cleaner air and water. These organisations – universities, research institutes and environmental organisations – should form key partners for the city and have crucial roles to play before environmental monitoring can begin – calibration, modelling and mix of sensor types.

Universities are able to help the city design the parameters for a successful environmental monitoring service. They can help with understanding the impact of pollution and how behaviours are linked to environmental quality. Environmental agencies are able to assist with helping the city understand various legislative requirements that they need to adhere to as well as assist identify funding sources. Many local or national agencies publish precise targets that the city must aim for. Healthcare agencies are able to help the city understand the impact of poor air and water quality. Incidences of disease and poor health directly attributable to poor air and water quality can be highlighted and used by the city as a key metric to monitor the effect of poor environment on the health of its citizens, and justify further investment in environmental monitoring and management.

INTERNET OF THINGS

Partners specialised in the Internet of Things are crucial to the success of any environmental monitoring services. IoT based sensors to be installed need to be connected, maintained and managed in order to extract the relevant information from them. A strong communications network partner is a necessity to ensuring that the service can operate effectively. Some of the areas that a communications partner can assist with include sensor calibration, data fusion, sensor connectivity and management, and the correct installation of the environmental monitoring devices.

Environmental monitoring equipment must be calibrated correctly before it is used. This falls into two areas. Firstly, calibration of the IoT sensors to local conditions, including temperature and humidity. Sensor performance under different environmental conditions needs to be understood so that data models can be adjusted accordingly. Secondly, properly calibrated smaller sensors can be combined with higher quality environmental monitoring stations to obtain a good picture of a whole area, with the more flexible sensors providing the ability to drill down into precise locations to understand the environment at that point and time. This is known as data fusion and allows data from many low accuracy devices to be combined to create higher accuracy results. Different IoT device types measuring different attributes such as air quality, wind or flood will also have to be placed in locations best suited to what they are sensing. The suitability of environmental monitoring is also important in ensuring that accurate data is obtained, and sometimes other IoT devices need to be added into the mix. For example, wind may play an important role in variation of air quality, and so measuring wind close to or at the point of measuring air quality is something that should be considered. Low cost and portable equipment has the potential to make a major difference in environmental sensing across cities, and effectively supplement existing environmental monitoring stations historically used for regulatory reporting purposes by providing enhanced insight.

Security is crucial when taking and processing sensor readings, to ensure trust in sensor readings is maintained. Mobile IoT is designed to be secure, and all data gathered and transmitted is secured end-to-end meaning that it cannot be accessed by those without authority.

An IoT Platform is essential to manage the devices and sensors that are to be installed in the field. Not only does an effective IoT platform allow device management, ensuring that all sensors and devices are operating correctly, it also allows for full management of the data generated by an environmental monitoring service and can ensure that any analytics requirements are adequately served. New devices and sensors can be added to the network simply, and all operations can be managed centrally without having to visit IoT devices in the field to perform maintenance. A mobile operator will be well placed to advise on how to use an IoT platform at the heart of an environmental monitoring service.

Network coverage is crucial for environmental sensors. Ensuring no compromise on location improves the relevance of data collected. NB-IoT and LTE-M are Low Power Wide Area networks from mobile operators, known as Mobile IoT. They offer wide area coverage based on existing mobile networks. Designed to improve coverage for IoT sensors, they penetrate deeper indoors than existing networks so they can be used across a city.

Maintenance of environmental sensors can be expensive, so Mobile IoT sensors offer a very long battery life so that once installed, sensors do not need to be re-visited.

Further information can be found at **www.gsma.com/MobileIoT**

IOT ANALYTICS AND INSIGHT

IoT platforms from mobile operators play a crucial role in the ongoing success of managing an IoT enabled environmental monitoring service. However, IoT data on its own does not tell the whole story. Large amounts of additional value and intelligence can be derived by integrating different data sources together to get a complete view of local environmental conditions and what maybe affecting them. Many different data sources are available to the city from a range of sources and sensors. This data can be in real-time or focus on historic trends and can include weather, traffic, satellite, population densities and health issues amongst many others. Mobile location data can be used to tie all of these together.

When these different data sources are integrated, valuable insight can become clear. Traffic patterns can be matched to pollution hotspots. Weather can be matched to water levels, and healthcare needs can be mapped to weather, pollen and pollution measurements. Ensuring that these data sets can be processed together means that a common format should be specified and using to minimise the integration effort needed when data is generated. Being able to identify every data set by the source that generates it and ensuring that disparate data sets have a common format means that intelligence can be generated quickly and cost effectively, allowing timely decisions to be made with confidence.

Once data is available in a format which allows processing, analysis of that data can be undertaken. Real-time data requires a different approach to historical data trends, although in practice one maybe overlaid over the other to gain maximum insight. Real-time data analysis may be performed by the network operator to ensure that timely insight is provided. When monitoring environmental conditions that can change quickly such as flooding, the faster the network, the quicker the data alerts can be delivered to the authorities that need them. Real-time analysis in this instance may be minimal, but can still be enhanced by other data such as weather, which can give indicators of likely issues that may arrive. Historical data can be stored and accessed at any time. This means that trends over time can be identified which makes data analysis even more accurate and allows city decision makers to both have confidence in decision making and also see the impact of any changes that have been made.

IoT big data allows for the sharing of IoT and context data so solutions utilising data from multiple sources can be developed. For environmental sensors, sensor data could be combined with weather, air quality, traffic and other data to provide an analysis of the environment across a city and how issues may be caused, allowing remedial actions to be taken.

Real-time data also means that automated responses to emergency situations can be prepared for when needed. A city facing a major storm or a forest fire, for example, can use environmental and weather monitoring as an early warning system to automatically alert emergency services to dangers as they arise, and set-off pre-planning response plans.

Collaboration with local groups and openness of data generated are also key tools in enabling the city to understand and resolve environmental issues. Longer term, making the data collected available to scientific and educational institutions for additional analysis means that the city is both playing a role in environmental security for the future, educating for responsible behaviours and also gaining insight in how well their city is performing compared to international averages.

The GSMA and its members have agreed harmonised data models for environmental monitoring. Common data formats mean that data can be more easily synthesised across a range of devices and partners, meaning effort and costs can be focused on the more valuable analytics effort.

Further information can be found at **www.gsma.com/iot/iot-big-data**

Communications Technology Procurement

Communications and big data technology drives the success of IoT enabled environmental monitoring and it is important to make the right choices. Cities and other bodies responsible for the local environment need to be sure that their technology selections are fit for purpose and will provide a base for building new services into the future.

Choices today will need to be used throughout a critical period of smart cities growth, and will need to adapt to many technological and behavioural changes on the horizon as new environmental initiatives are introduced from electric vehicles to ecological changes caused by climate change. Selecting a solution which will not adapt to future needs could be a costly mistake.

Cities and environmental bodies need to take a holistic approach to their choice of communications and platform provider and should be thinking of several questions to ask, such as:

Interest	Question	Answer is relevant when
Performance	Is the system able to scale to meet your demands?	You intend to connect more than one location; you intend to have real-time updates
	What are the message delivery times?	You want to use the system to provide real-time alerts and data analysis
	What is the network coverage?	You intend to offer a service across a city or rural area; you intend to monitor the environment in buildings
Data	Does the service support open data formats?	You intend to use multiple IoT device types to record different parameters across a city
	Does the platform support Big Data?	You intend to analyse data for trends or have an overall view of environmental impacts by combining with other data feeds
Security	Does the network support end-to-end encryption and authentication?	You need to meet a required security or privacy standard
Communications Infrastructure	Does the network operate in licensed spectrum?	You value high quality of service and low risk of interference
	What additional infrastructure is needed to support the service?	You want to keep your capex costs low; You don't want a complex implementation
	Can the service provider be changed?	You want to avoid vendor lock-in and re-negotiate contracts periodically
	Does the service have a roadmap to new service features?	You want to take advantage of new service features as they are introduced

Partnerships

Cities and environmental bodies should be looking to achieve long term, flexible partnerships with their suppliers. All stakeholders in the value chain should be seeking a mutual relationship with each other that allows for flexibility in environmental monitoring provision and use of technology to create efficiencies, build better services and open data to the public.

When looking to establish partnerships with mobile operators and other suppliers, cities and environmental bodies should ask themselves how they can maintain openness and gain the best cost to operate an environmental monitoring service. This may mean strategies such as outsourcing monitoring operations or entering into procurement partnerships with other cities should be considered.

A smart cities vision is also key to ensuring that the partnerships for environmental sensing are a success. Procuring a service in an environment which is defined by a strategic approach across all city departments means that projects and procurements can be executed in confidence. For example, ensuring that the transportation department is aligned with clean air plans means they are likely to be more successful. Collaboration across different departments ensures that data gathered can be applied into other systems, experience can be shared and failures are less likely to occur.

BUSINESS MODELS

The deployment of an environmental sensing service offers cities and environmental bodies a fresh approach to how they distribute relevant data and manage the impacts that the environmental monitoring highlights. There may even be ways to monetise data sets in order to fund ongoing initiatives.

Partners such as app providers and educational and research establishments offer new ways to monetise environmental data, and allow the cost of deployment and ongoing management to be spread in new ways. For example, app providers maybe able to highlight air quality issues, or be used to route traffic in different ways to ensure clean air can be maintained. Weather forecasters can use the sensing data to improve their forecasting models and offer real-time hyper-localised weather alerts to users.

The data available from environmental monitoring can be linked into other data sources to create new revenue sources for the city. When air quality is bad, vehicles could be charged more for entering the cities boundaries. Alternatively, fines could be levied against heavy polluters of air and water, especially if pre-set targets are not met.

The financial model for deploying environmental monitoring can be innovative in its approach for the reasons outlined above. Budget constraints can be addressed through alternative funding models, with grants, asset leasing and smart investment models all being used to alleviate traditional funding constraints. Existing smart infrastructure, such as connected streetlights, provides a readymade base to build a monitoring network out from and could also create a new way of funding if the benefits of these projects can be combined.

KPIs

Cities and environmental bodies must define desired outcomes before embarking on an environmental monitoring deployment, use these outcomes to define KPIs in the service scope and ensure that potential partners are aware of what is needed to be delivered by the live service.

To go further, KPIs can be used to develop a programme framework which can demonstrate the relationship between behaviours and wider environmental impacts on the city. So if one of the cities strategic objectives is to reduce pollution from traffic, environmental monitoring should be able to link to parking data for example, to show that perhaps increased parking prices discourage traffic and thus pollution. This in turn means that the business case for deploying environmental monitoring can become more dynamic with benefits shown across the city.

Typical KPIs that the city or environmental bodies may want to investigate include:

Environmental parameters	Environmental management
■ Gaseous – NO_x, O_3, CO etc ■ Water – O2 levels and pollutants ■ Pollen ■ Air-borne particulates – PM_{10}, $PM_{2.5}$ ■ Temperature ■ Humidity ■ Noise (dB)	■ Resource usage ■ Environmental performance of products and services ■ Clean air zone management ■ Industrial emissions management ■ Transport emissions management
Links with other services	**Technology Characteristics**
■ Emissions penalty charging ■ Energy efficiency ■ Congestion and parking charging ■ Open Data availability for apps etc ■ Environmental hazard warnings	■ Number of messages sent/received ■ Message delivery success rate ■ Message latency ■ Battery life of sensors ■ Open data access ■ Network coverage

Tracking of performance and benefits will be key to ensuring that any environmental monitoring or management service is a success. Monitoring these KPIs against pre-set objectives will allow performance targets to be met. For example, penalties can alter behaviour quite significantly. Any problems that are identified will need to have ownership and mitigation plans to prevent loss of stakeholder engagement.

Route Maps

Implementing environmental monitoring requires an approach that is flexible and able to engage relevant stakeholders in changes needed to make maximum advantage of any investment.

“Starting small” is a good way to get up to speed with new methodologies whilst reducing the risk of mistakes which are difficult to reverse. Building upon this initial step with a series of iterative changes as the project grows will ensure that the full commercial service is more likely to be sustainable and deliver citizen engagement. The core stages of growth for an environmental monitoring service are outlined below.

STRATEGY & SCOPE	PILOT	ESTABLISH	SCALE	EVOLVE
Identify issue to be resolved	Refine processes	Incremental Go-live	Scale to multiple sites	Monitor performance
Define required outcomes	Test network performance	Live data integration	Introduce new public services	Adjust service parameter if needed
Secure budget commitments	Understand installation needs	Apply lessons learnt and changes	Publish open data APIs	Undertake maintenance
Secure stakeholder commitments	Generate test data	Establish trusted foundation system	Integration with city dashboard	Sharing learnings with other cities

ENVIRONMENTAL MONITORING				
Identify issues that need resolving	Ensure data formats are open and accessible to stakeholders	Establish trust in sensor readings	Ramp-up installation in wider areas	Monitor performance against baseline
Research regulatory requirements	Test network performance	Undertake data integration with other systems	Introduce public data APIs	Use data to inform future regulatory decision making
Build requirements for data collection	Audit locations for environmental sensors	Undertake initial data analysis	Use data for regulatory reporting requirements	Introduce new drivers to create environmental improvements
Understand how national plans affect city deployments	Perform initial calibration of sensors	Prioritise areas with high environmental impacts	Refine data models and sensor calibrations	Demonstrate behaviour changes compared to other cities
Understand learnings from other cities				

SCOPE AND STRATEGY

Cities and environmental bodies need to define their objectives before setting out to procure environmental sensors or platforms. The strategy and scope that the city or adopts will dictate key decision points throughout the implementation and lifetime of the system.

Factors that will influence the strategy include the current issues and the desired changes and outcomes to be bought about in the cities environment. This will be influenced by the budget available, size of the deployment, and the role of the various stakeholders in the city.

Once a city has resolved all of these points, it can pull together a strategy and begin to build a list of requirements to go to market with. Critical to ensuring the success of this strategy is the commitment of all stakeholders across the value chain.

PILOT

A small scale pilot is a good way to ensure that the IoT sensors are able to collect data effectively, processes that have been scoped around the project are fit for purpose, and that every stakeholder is clear of their role. Amongst the deliverables that should be investigated at this stage are – Data security, data formats, network performance and installation processes. However a pilot should only been seen as a temporary measure, and the project should quickly move on to ensure time and energy are not wasted in over analysing all aspects of a service. The city should also look to other bodies who have implemented environmental monitoring to gather lessons learned. Many sensor providers are entering the market, which is a sure sign that the pilot phase is something which will soon not be needed at all. With many vendors to choose from, implementation expertise will become more widespread, meaning a city can confidently begin to implement a service without extensive testing first.

ESTABLISH

Once the pilot has been completed, cities should move quickly to establish a trusted system with incremental deliverables. It is best not to focus on all environmental aspects of the service at once, but ensure that environmental monitoring can come on line in an incremental fashion so that they can be perfected without impacting on rollout timescales. By phasing the approach, the city can increase confidence in the systems being deployed and ensure that stakeholders have a clear view of the success of different environmental monitoring systems.

SCALE

During the phased growth phase, the programme may still only be focussed on one site or one service. Once enough confidence has been gained in the system and the required processes have been proven to operate effectively in a live environment, the system can be scaled across multiple IoT device types and sites. However, care must be taken to ensure that each device type is calibrated correctly. Open data APIs can now be published to allow developers and other stakeholders to start building innovative solutions. At the point of scale, the city can also start to introduce new concepts to businesses and citizens such as incentivisation for good environmental behaviours.

EVOLVE

Once the environmental monitoring service have been fully deployed, the city should review performance and understand how the service is impacting local management and if the city is performing effectively against environmental targets that have been set locally and nationally. As these new technologies drive change across the city, new services can be introduced and existing service re-configured to meet updated targets and ambitions. The use of open standards will ensure that future changes can be more easily managed. KPIs will need to be used to ensure that the environmental sensors continue to perform effectively and allow mitigation to be undertaken if issues are identified.

Conclusion

Smart environmental monitoring can be enabled today by Mobile IoT from mobile operators. Mobile operators are strong, low risk, long term partners, well placed to meet all the needs of an environmental monitoring and management service – secure communications network and management platform, access to open data and engagement with developers and platform providers. Mobile operators and Mobile IoT are also future proofed, as they are based on international standards with a roadmap towards integration with future networks and future smart cities needs. Mobile IoT also operates in licenced managed spectrum, so is a robust, scalable choice for all of a cities environmental management needs.

Cities initiating environmental monitoring projects need to consider their mobile operator as a core partner and work alongside them to scope and implement environmental monitoring and associated data analytics. Mobile operators can share their experience of previous deployments, offer economies of scale and understand the intricacies of how to deploy in different environments. All parties in the value chain can benefit from having a mobile operator at the core of a programme, as the data generated can be controlled and managed throughout the value chain in a consistent, accessible and secure manner.

Environmental IoT monitoring offer a city and other environmental stakeholders new ways to engage with the public and create important secondary benefits including economic growth and reduced traffic and pollution. The business model behind environmental sensing as a service is maturing now to a point where it is achievable, affordable and beneficial to a city. By ensuring that the cities strategy around communications, data and financing is robust, cities should move forward with their investigations and procurement of environmental monitoring services.

Floor 2, The Walbrook Building
25 Walbrook, London EC4N 8AF UK
Tel: +44 (0)207 356 0600

smartcities@gsma.com
www.gsma.com/smartcities