# A LOW COST WIRELESS ENVIRONMENTAL SENSOR SYSTEM FOR ROAD NETWORKS

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**ABSTRACT**

This paper describes the on-going research at Newcastle University in the MESSAGE project which is a major environmental monitoring project funded jointly by the EPSRC and DfT. The MESSAGE project investigates the use of low cost wireless sensors and their deployment to create a dense, pervasive, ad-hoc network for monitoring traffic pollution in a road environment. Each of the wireless devices carries one or more sensor payloads which will capture one or more of the pollutants directly associated with road vehicle emissions. This paper will provide an overview of the deployment of a MOTES network in Gateshead, UK, to measure a variety of pollutants and also explore whether other pervasive sensors, such as vehicle detectors can be included in the overall monitoring package. The research will cover three distinct areas: the network development; the applications developed for monitoring pollutants; and an investigation as to how the data collected could be used to validate and calibrate emissions and dispersions models. A final step will be to explore how this vast array or real-time data could be used to modify and influence real traffic control schemes, to give environmental measurements a clear, policy-sensitive role in future traffic management and control schemes.

## 1 Introduction

A recent study by the UK Governments Office of Science and Innovation, which examined how future intelligent infrastructure would evolve to support transportation over the next 50 years looked at a range of new technologies, systems and services that may emerge over that period [4], [13]. One key class of technology that was identified as having a significant role in delivering future intelligence to the transport sector were wireless sensor networks and in particular the fusion of fixed and mobile networks to help deliver a safe, sustainable and robust future transport system based on the better collection of data, its processing and dissemination and the intelligent use of the data in a fully connected environment [22]. As future intelligent infrastructure will bring together, and connect: individuals; vehicles; and infrastructure through wireless communications, it is critical that robust communications protocols are developed. Moreover, road networks currently are not widely fitted with wireless infrastructure, although the recent M3 trials by the Highways Agency and the 'intelligent corridor' trials in Newcastle (UK) both trialled such infrastructure [19].

Newcastle University has been embarking on a series of research projects over the past few years to examine the feasibility of using low-cost, miniature wireless sensors for a range of transport-related applications. The reason this new class of wireless sensor is of interest to the ITS community is that these wireless sensors are predicted to become very small and very cheap within a decade.

These wireless sensors are designed to form unconventional ad-hoc networks, which means, they form random communications networks with any other like-wireless device that is in (communication) range, similar to how wireless Bluetooth devices connect together when in range (i.e. a printer, PC, data-projector, mobile phone and ear-piece etc.). However, for future ITS applications, prototypes have been evaluated using frequency bands around the 800-900MHz, 2.45GHz and 5.8-5.9GHz using communication protocols including IEEE 802.11x (WiFi) and IEEE 802.15.4 (Zigbee). Trials in several projects have shown the robustness of the communications and associated protocols, for both static and mobile (infrastructure to and from moving vehicle) applications. This powerful new communications tool, coupled with the ability for these devices to be fitted (or integrated) with sensor payloads, will offer a new opportunity for pervasive communications and sensing, as the size and cost of these devices reduce so they can be embedded in everyday objects. From a transport point of view, this means within street-side furniture, road surfaces, vehicles and within devices travellers carry, or even purpose built wearable interfaces. These small low-cost devices that we aspire to develop, have been described by the term 'smartdust', however the term MOTE (a biblical term for a grain of sand) tends to be used by researchers as the current favoured term. To manage expectation, in Newcastle we tend to use the term for the prototype devices of 'smart-lumps'.

By their very nature, Mobile Ad-hoc Networks (MANETs) are self-organising mobile networks where nodes exchange data without the need for an underlying infrastructure. In the road transport domain, schemes which are fully infrastructure-less and those which use a combination of fixed (infrastructure) devices and mobile devices fitted to vehicles and other moving objects are of significant interest to the ITS community as they have the potential to deliver a 'connected environment' where individuals, vehicles and infrastructure can co-exist and cooperate, thus delivering more knowledge about the transport environment, the state of the network and who indeed is travelling or wishes to travel. This may offer benefits in terms of real-time management, optimisation of transport systems, intelligent design and the use of such systems for innovative road charging and possibly carbon trading schemes as well as through the CVHS (Cooperative Vehicle and Highway Systems) for safety and control applications. Within the vehicle, the devices may provide wireless connection to various Information and Communications Technologies (ICT) components in the vehicle and connect with sensors and other nodes within the engine management system.

## 2 Current Portfolio of Projects

Newcastle University has been at the forefront of research into the technology challenges of using these small, low-cost and smart wireless sensors in Transport and the application areas where they could be employed. It is clear to the ITS community that the emergence of low cost sensors will open up new paradigms in how we can pervasively collect data from sensors, convey information along fixed and mobile low cost wireless networks (partly or fully formed or ad-hoc) and provide pervasive connectivity between people, vehicles and infrastructure. A number of the key projects undertaken in this area are briefly described below:

### 2.1 Applications of Smartdust in Transport (ASTRA)

The ASTRA project [3] investigated the use of mobile ad-hoc networks, and more specifically, smartdust for transport applications. The project examined the current state-of-the-art with smartdust, using MICA2 motes [18] as the technology to be tested. It also looked at the likely market and technological advances of the smartdust technology over the coming decade.

A trial using smartdust technology was hosted in Newcastle with a pervasive intelligent corridor established by a network of fixed motes on roads near Newcastle Central Station. Mobile motes were also placed in several buses. Communication between a static mote and a moving mote on-board a vehicle was achieved, showing that communication can take place between road side and vehicles using a network of motes [6].

### 2.2 Technologies for Road Advanced Cooperative Knowledge Sharing Sensors (TRACKSS)

The focus of the EU funded TRACKSS project [21] is to research advanced communications concepts, open interoperable and scalable system architectures that allow easy upgrading, advanced sensor infrastructure, dependable software, robust positioning technologies and their integration into intelligent co-operative systems to support a range of core functions in the areas of road and vehicle safety and traffic management and control. The overall aim is to develop new systems for cooperative sensing and predict flows, infrastructure and environmental conditions surrounding traffic, with a view to improving road transport safety and efficiency. To support the demonstration phase of the project, Newcastle University will develop a new technology for ‘smart’ detection on vehicles and infrastructure and a common framework for data collection and access from the entire array of sensors being deployed and tested in the TRACKSS project.

### 2.3 Embedded Middleware in Mobility Applications (EMMA)

The EMMA project [1] is funded by the EU and has an overarching goal of utilising new embedded middleware to support the underlying logic and communications required for future cooperating wireless objects and the applications they may support in the automotive and road transport domains. This trend in the deployment of digital processing widely into the environment – what is variously called ambient intelligence, ubiquitous computing, the internet of things, or just ‘smart’ technology – goes well beyond transport and will impact on almost every aspect of our lives. Just as the World Wide Web was a one-time transition in the technology landscape, bringing information into a globally integrated system, so we are just at the start of another one-time transition, linking up things through embedded intelligence and communications.

In the case of EMMA, the things being automobiles and their constituent parts, and the infrastructure they utilise (both physical in the sense of roads and the ICT embedded in them for monitoring and control purposes). If we think more widely at present, most of the world’s computing power is already embedded invisibly into the things around us. The personal computers, music players and other gadgets are just the tip of the iceberg. They probably represent no more than 1% of the computing power we have deployed around us. A typical car today will have at least 20 microprocessors and a host of other electronics contributing to the general functionality required by a modern car as well as the ‘value added services’ which may be the USP (Unique Selling Point) of a particular vehicle – whether the application, be: better information on how the vehicle is running; safety applications; or infotainment in the vehicle to name but three.

The EMMA project is committed to deliver a middleware platform and a development environment which facilitates the design and implementation of embedded software for cooperative sensing objects. The ultimate aim that the project will focus on delivering, is to hide the complexity of the underlying infrastructure whilst providing open interfaces to 3rd parties enabling the faster, cost-efficient development of new cooperative sensing applications. This end-product will be accompanied by a publicly available specification (PAS) that will help to facilitate its wider adoption.

### 2.4 Ambient intelligence System of agents for Knowledge-based and integrated services for mobility impaired users (ASK-IT)

ASK-IT [2] uses ambient intelligence technology to provide functions and services for older and disabled people in various environments, including home, work, leisure and transport. The main features include: mediation of content and services; seamless environment management (anywhere, anytime); user preference and context-related processes; flexible geo-referenced services; and a user confidence based environment. The first phase of the research involves the collection of info-mobility content relating to the environments described above. In the leisure and tourism sector, for example, this might include details of accessibility to cinemas, sports venues or restaurants. This content is then integrated with different tools, including enhanced accuracy localisation, accessible inter-modal route guidance modules, and interfaces to e-commerce/e-payment, e-working, e-learning systems and assistive devices. It is envisaged that this framework will be interoperable in terms of mobile devices and local and wide area networks. The integrated ASK-IT services and system will be tested in a number of interconnected cities/areas across Europe, to prove that accessibility for disabled users can be achieved in a reliable, seamless and viable way, using a range of available technologies and communication networks. Newcastle is developing a wireless network for outdoor navigation and localisation system that can inform and assist mobility impaired travellers in a range or urban environments when travelling and visiting points of interest [10].

### 2.5 Foot-LITE

The Foot-LITE project [12] is funded by the UK EPSRC, DfT and Department of Trade and Industry (DTI) under the joint FITS (Future Intelligent Transport Systems) initiative. The project will deliver innovative driver/vehicle interface systems and services to encourage sustained changes to driving styles and behaviours which are safer, reduce congestion, enhance sustainability, help reduce traffic pollution emissions, and reduce other social and environmental impacts. Fundamental research will be used to support the strong industry base in the project through prototype systems development and design, impact assessments and the further development of research tools and processes to deliver a credible evidence-based validation of the system through to real-world operational experiences with user feedback and evaluation.

The Foot-LITE system is seen as a tool to encourage and challenge drivers to achieve very real benefits that are already available in the current vehicle fleet but whose benefits cannot be readily maximised without an advisory interface to the driver. The approach has the ultimate choice and control still resting with the individual. This is seen to be crucial to the public and commercial acceptability of Foot-LITE. The aim of the Foot-LITE project is to create a revolutionary driver information system designed to educate and encourage safer and greener driving and longer term behavioural changes. The vehicles will be in communication with a wireless network established at the roadside for environmental monitoring and control functions.

### 2.6 Mobile Environmental Sensing System Across Grid Environments (MESSAGE)

The MESSAGE research project [5] is an important new initiative involving five universities, and funded jointly by UK Engineering and Physical Sciences Research Council (EPSRC) and the Department for Transport (DfT). The project involves developing new techniques for collecting, managing and interpreting data on environmental quality and its relationship to transport. The overall aim of the project is to address key scientific challenges in the field of transport and environmental monitoring, using data derived from transportable sensors which can measure local environmental factors such as pollutants from vehicles.

Utilising the expertise and track record of the ITS research team, Newcastle University is developing and testing a wireless ad-hoc sensor network using smartdust to pervasively sense traffic pollution on the road network of Gateshead (UK). This is a unique opportunity to pervasively sense pollution generated from road traffic, through the deployment of up to 300 wireless sensors in the street-side infrastructure of Gateshead to measure pollutants and detect vehicle flows. The real-time monitoring of the environment pollution will be used to explore how traffic control and real-time demand management measures could be implemented to mitigate the pollution episodes. Once the science and technology research challenges are resolved at the Gateshead test site, a second set of wireless sensors will be deployed and integrated with the instrumented city facility in Leicester (UK) and tested with real traffic control strategies [15].

The MESSAGE project team in Newcastle builds on previous multi-disciplinary collaborations across the University and bring together the ITS and environmental team of the Transport Operations Research Group, with the wireless sensor group of the School of Electrical Engineering and the e-Science researchers of the North East e-Science Centre. This paper presents the concept and mid-stage research of the MESSAGE Project

### 2.7 Research Trajectory

These projects are beginning to deliver research evidence that the wireless ad-hoc networks can be used within the transport environment, for automotive applications (EMMA, TRACKSS and Foot-LITE), road to vehicle communications (ASTRA, EMMA, TRACKSS and Foot-LITE), sensor applications (TRACKSS and MESSAGE) and for personal communications and localisation (ASK-IT and MESSAGE). There are still key challenges with respect to robust protocols, miniaturisation, battery, antennae and sensor design, however the applications tested and evaluated are beginning to show that we are not too far away from having the ability to deploy these wireless low-cost sensor networks pervasively to enhance the management and control of transport networks and deliver new connectivity between people, infrastructure and vehicles.

## 3 The MESSAGE Project

### 3.1 Overview

The EPSRC MESSAGE project is currently investigating how increased spatial and temporal resolution in sensor data can improve urban traffic management compared to the sparse coverage provided by a small number of high-cost monitoring stations typical of most cities. Higher spatio-temporal resolution is also required to validate models of dispersion, traffic flow and noise propagation. The key enabling technology to achieve these objectives is a sensor device or 'mote' capable of measuring multiple parameters and relaying data via wireless communications. When a number of these devices are deployed in a network then the potential for pervasive environmental sensing can be realised. This device must be physically small, low cost (to enable large quantities to be deployed) and must operate for long periods from battery power or scavenged energy e.g. solar. Although numerous commercial mote products are already on the market [23], [18], none have the necessary sensor payload or flexibility in power management and communications. Hence a custom designed mote has been developed at Newcastle University to meet the requirements of the MESSAGE project and similar applications. Figure 1 shows the architecture of the custom designed motes.

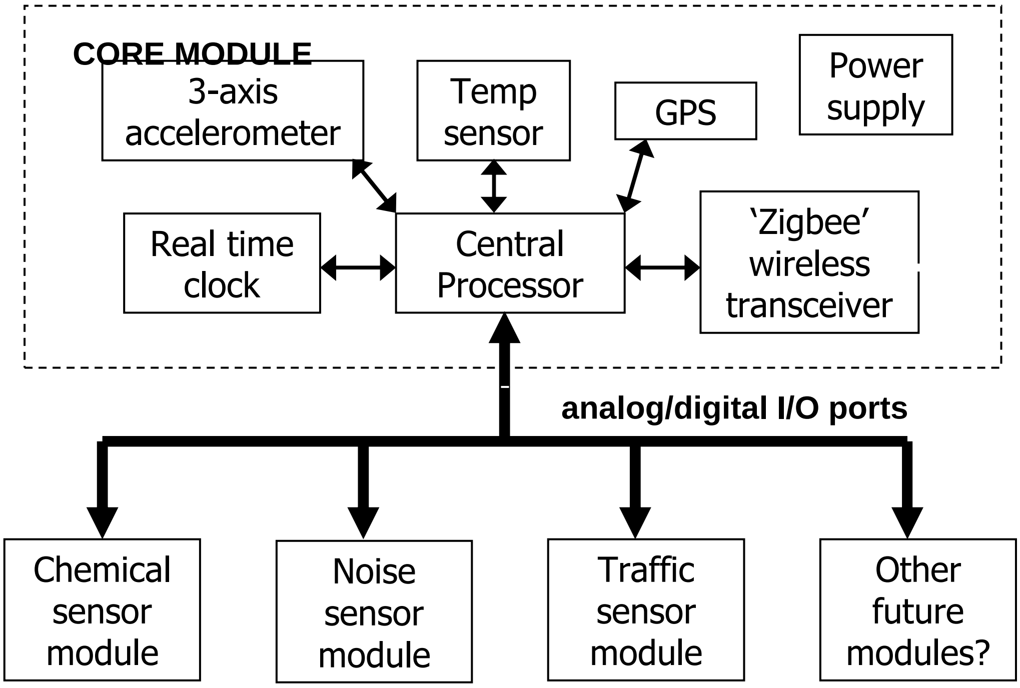


**Figure 1: Architecture of MESSAGE Motes**

### 3.2 Description of Prototype System

The key drivers in the design are cost, battery life and physical size and so it was decided to design the mote within the constraints of a 140 x 85 x 65mm housing with energy supplied by a single Lithium 'D' cell providing 19Ah at 3.5V. The target component cost for each mote was less than £200 in prototype form. Central to the design is an 8-bit, low power microprocessor (PIC18F4620) with a large number of digital and analogue ports. The architecture was also designed so that the processor core and some of the sensor/communications circuits can be powered down when not in use. This enables the power consumption of the motes to be precisely controlled, depending on the desired sampling rate, integration time and transmission schedule for the sensor data, to achieve battery life up to one year from the available cell. The motes are designed in a highly modular form to accommodate a wide range of possible sensors but the following sensors were chosen to meet the needs of the MESSAGE project:

- GPS to enable tracking of mobile motes or initialisation of fixed mote positions.
- 3-axis accelerometer to provide more information on mobile motes and possibly low frequency vibration data.
- Digital temperature sensor.
- Low drift (< 2min/year) real time clock (RTC) for time stamping of data and network synchronisation.

- Chemical sensor module measuring carbon monoxide (CO) and nitrogen dioxide ($NO_2$) as minimum. Relative humidity sensor also incorporated.
- Acoustic noise sensor.
- Traffic sensor to provide estimates of vehicle flow/density.

A wireless transceiver is included which implements the Zigbee communication standard to provide power-efficient networking over point-point ranges of up 100m. The communication and sensor modules are each discussed in detail in the following sections. The final mote constructed is pictured in figure 2.

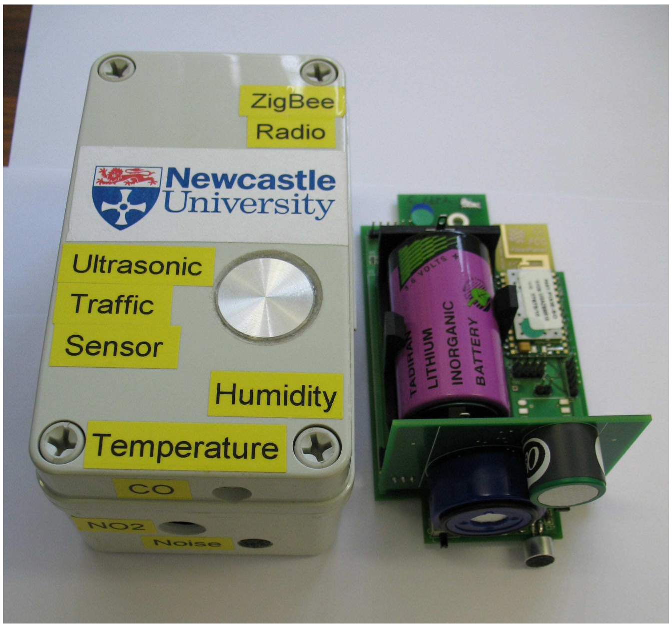


**Figure 2: MESSAGE Mote Packaging and Electronics**

### 3.3. Communications and Data Collection

Although each mote could be equipped with a GSM modem to transfer data via existing mobile telephone networks this option is both expensive (both hardware and network charges) and requires significant energy. The project aims to densely populate an area with motes and hence this lends itself to the creation of a mesh network topology, as shown in figure 3, using licence-free, low power radio technology. IEEE 802.15.4, commonly known as Zigbee, is an open standard providing wireless networking in the 2.4GHz ISM band at data rates up to 250kbits/s and ranges up to 100m [14]. Its main advantages for this application are low cost (transceiver chips cost <4 USD), low power consumption and small antenna dimensions. The radiated power is typically 0dBm (1mW) which is several orders of magnitude smaller than GSM or WiFi.

Data and control packets can be transferred through the Zigbee enabled mesh network using multi-hop routing protocols. By using a mobile ad-hoc network (MANET) protocol, such as AODV [17] employed in this system, optimum routing is maintained as nodes move in/out of range or if nodes fail. Using this topology, with 200+ motes (the maximum target number for deployment in Gateshead), an area of approximately 2km$^2$ can theoretically be covered, with the intelligent routing algorithm compensating for obstructions in connectivity expected in an urban site. The data is routed toward one or more GSM equipped 'gateway' nodes (with hard-wired power) which transfer to a server at Newcastle University running a UTMC compliant database.

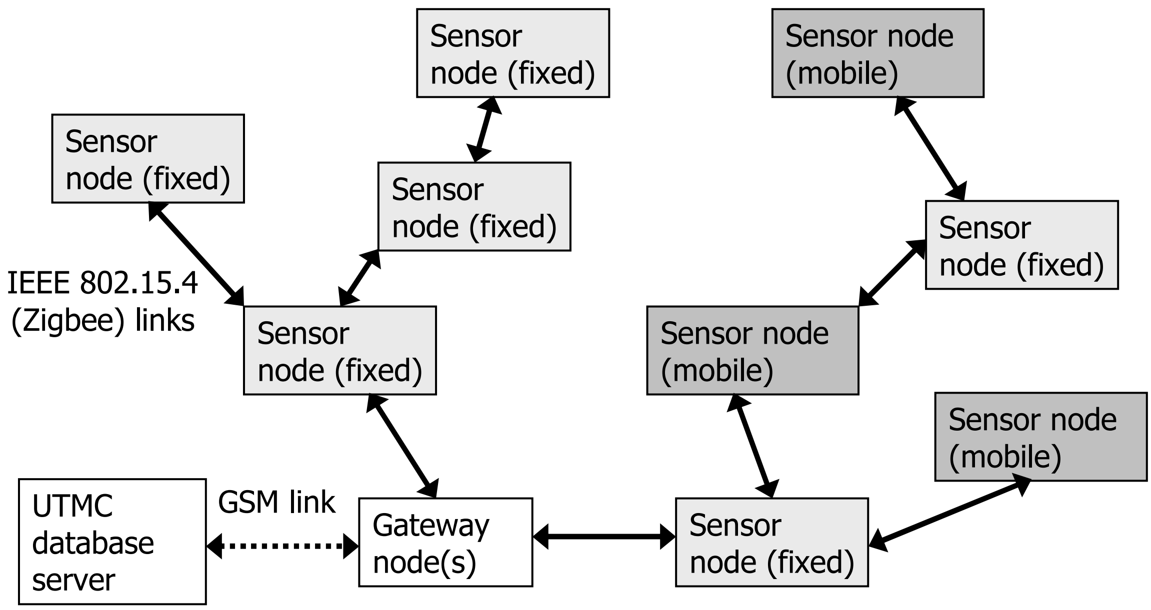


**Figure 3: MESSAGE Communication Network Topology**

### 3.4 Progress to Date: The Gateshead Trial

To date several dozen sensors have been deployed to test the robustness of the wireless sensor network and the ability of the network protocol to handle the date generated by the sensors and to pass this data through the MANET to gateway nodes. Initial tests have been promising and a stable design for the prototype motes for the Gateshead trial have now been finalised, with 60 motes now being constructed for the first phase of the Gateshead trial. The location of the prototype sensors for deployment in Gateshead has now been made in collaboration with Gateshead council, with a number of sensors being co-located with fixed environmental sensors and traffic counting sensors in Gateshead so that additional calibration tests can be carried out. The initial tranche of motes were installed in Gateshead on the 17th July 2008 around the main interchange roundabout leading to the Tyne River Crossings to Newcastle, as illustrated in Figure 4.


**Figure 4: Location of Experimental Motes in Gateshead.**

Initial calibrations of the environmental sensors was carried out by co-locating sensors with fixed sensors at the *instrumented city* (IC)facility near Leeds. The results for the two chemical sensors that measure $NO_2$ and CO are of particular interest, however the calibration results have so far been excellent. The key point with these low-cost sensors is how long the sensors will remain calibrated before they drift. This work is on-going. Figure 5, below shows the trace of the calibrated $NO_2$ sensor from the IC (in black) and the mote chemical sensor (in red).

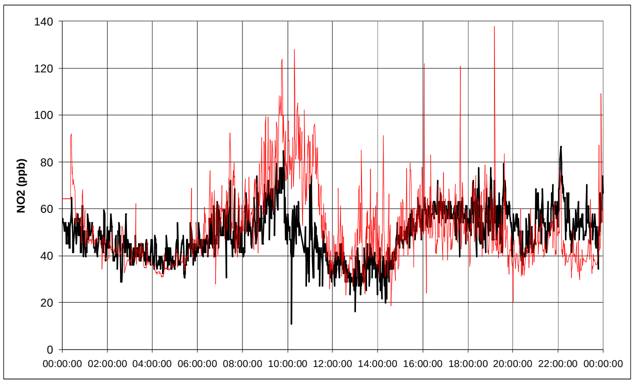


**Figure 5: Comparison of $NO_2$ sensors over a 24 hr period**

In parallel with the research into the wireless sensors and the establishment of a wireless sensor network, another key area of current research within the MESSAGE project is the development of a UTMC compliant data-base to input, store, process and integrate with historic data.

The initial UTMC data base is presented in another paper at this conference. Significantly, a web-based interactive map has now been developed along-side the data base so that each wireless mote node can be 'clicked' on, on a map and the current sensor data collected by each mote ($NO_2$ ,CO, temperature, humidity, noise and traffic count) can be displayed in real-time (Figure 6)

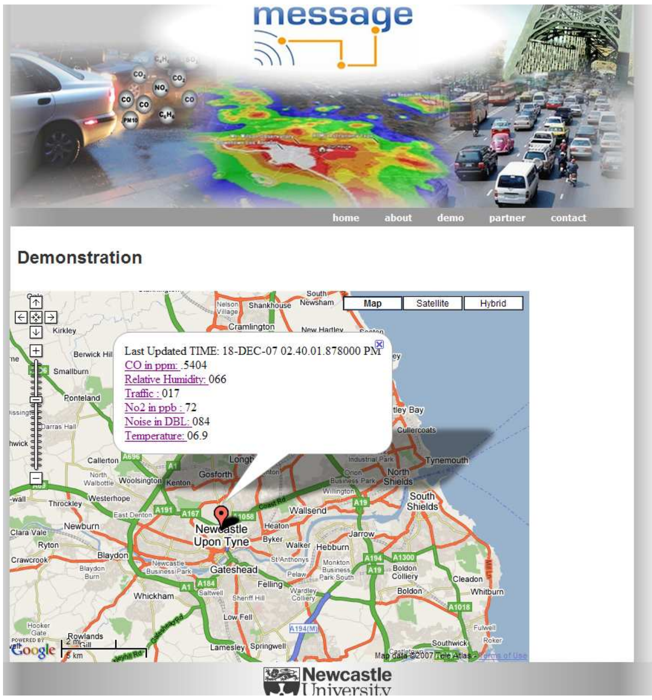


**Figure 6: Clickable Web-Map with data available from each Mote location.**

An add-on to the MESSAGE project has been the integration of an ultrasonic sensor to the mote package. The ultrasonic senor is being tested as a low-cost way of counting vehicle passages on the lane adjacent to the mote location.

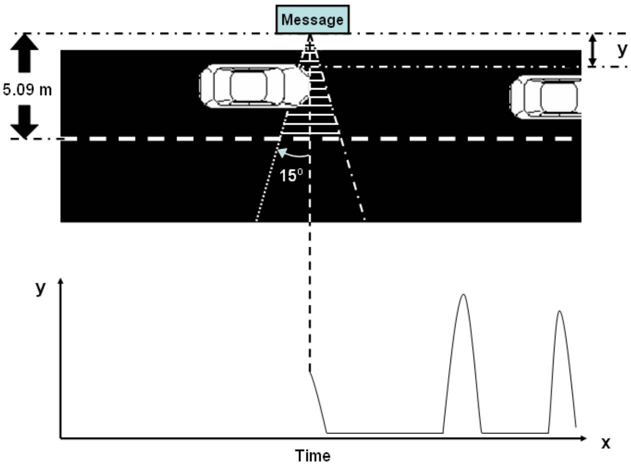


**Figure 7a: Experimental Set-Up to Test Ultrasonic Sensor**

The sensor is available at a cost of less than £10 and uses a 40KHz frequency ultrasonic transceiver with a programmable range of up to 5m. Initial results show a better than 97% accuracy, compared to a ground-truth Commercial traffic sensor.

Figure 7a shows the experimental set-up of the traffic counting sensor and 7b shows the counters results compared to a ground-truth sensor.

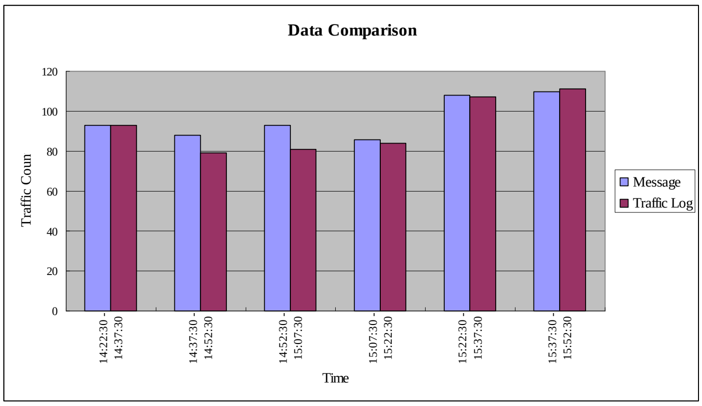


**Figure 7b: Comparison of Traffic Count Performance of Mote Sensor and a Ground Truth Sensor**

The integration of this sensor with the MESSAGE mote package will offer a significant increase in the performance of the sensor network and the ability to deploy a low-cost package of sensors for traffic management applications. From the initial deployment in July 2008, results are on-line from a network of 17 motes installed around the main roundabout at Gateshead and they are continuously logging data at minute intervals on the gateway PC in the AQM cabin. The map in figure 4 shows the approx locations of the motes with red numbers indicating motes with traffic sensor enabled. All motes are logging CO, NO2, noise, temperature and relative humidity. Motes 48, 49 and 50 are also acting as routers where line-of-sight does not exist back to the gateway. The plots below (Figures 8a-8d) show from midnight through the rush hour on 18/7/08 with mote 36 providing traffic occupancy data for the roundabout discharge towards Newcastle and mote 34 providing air quality and noise data in close proximity to habitations close to the roundabout. (NOTE: gas concentrations are un-ratified as yet but trends are clearly visible).

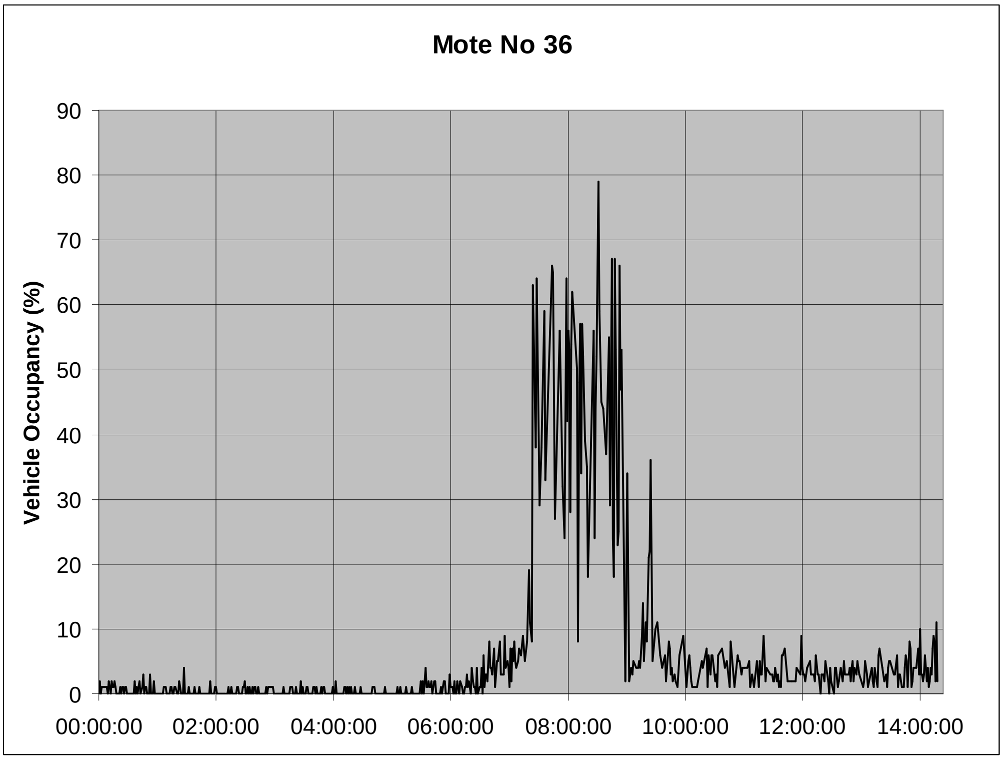


**Figure 8a: Midnight to 2pm data on Vehicle Occupancy from Mote #36**

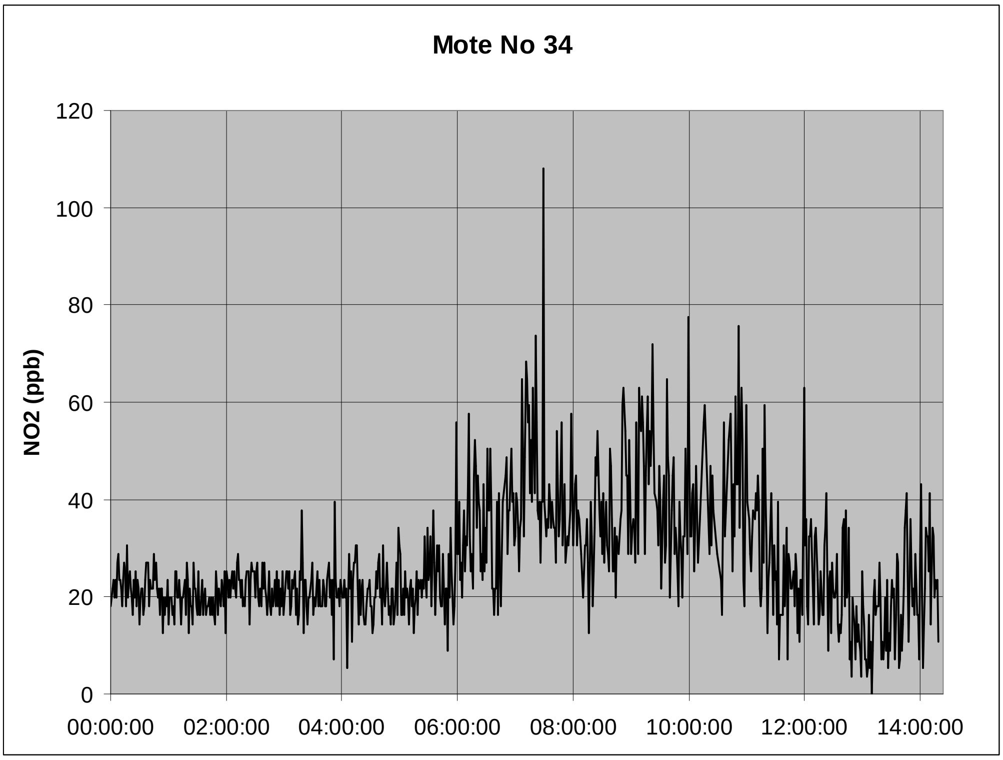


**Figure 8b: Midnight to 2pm data on NO2 levels from Mote #34**

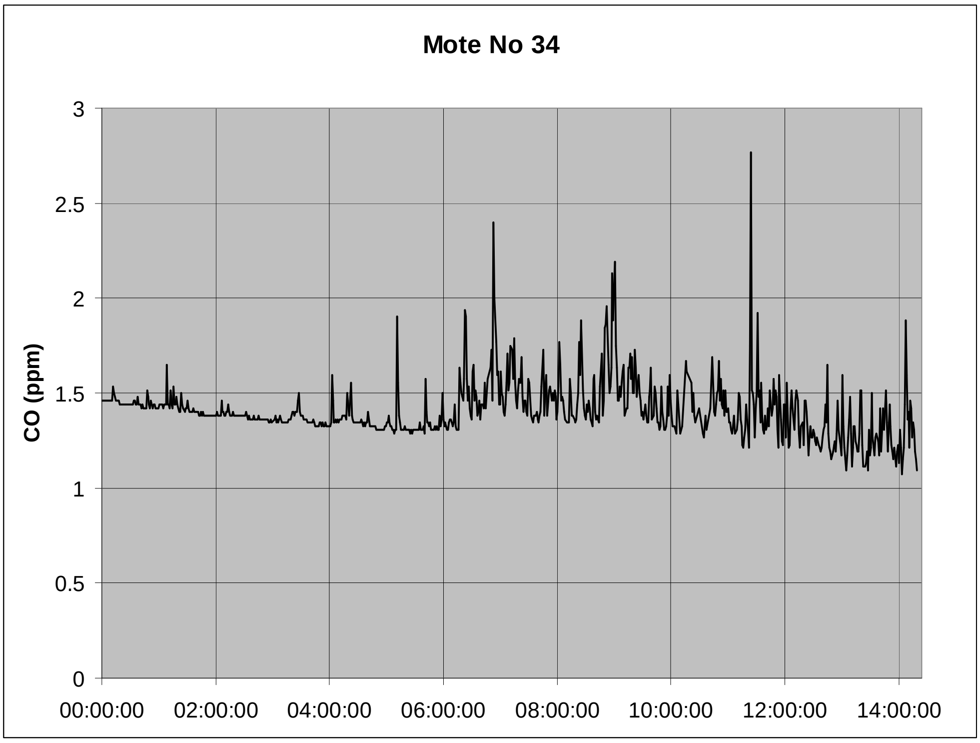


**Figure 8c: Midnight to 2pm data on CO levels from Mote #34**

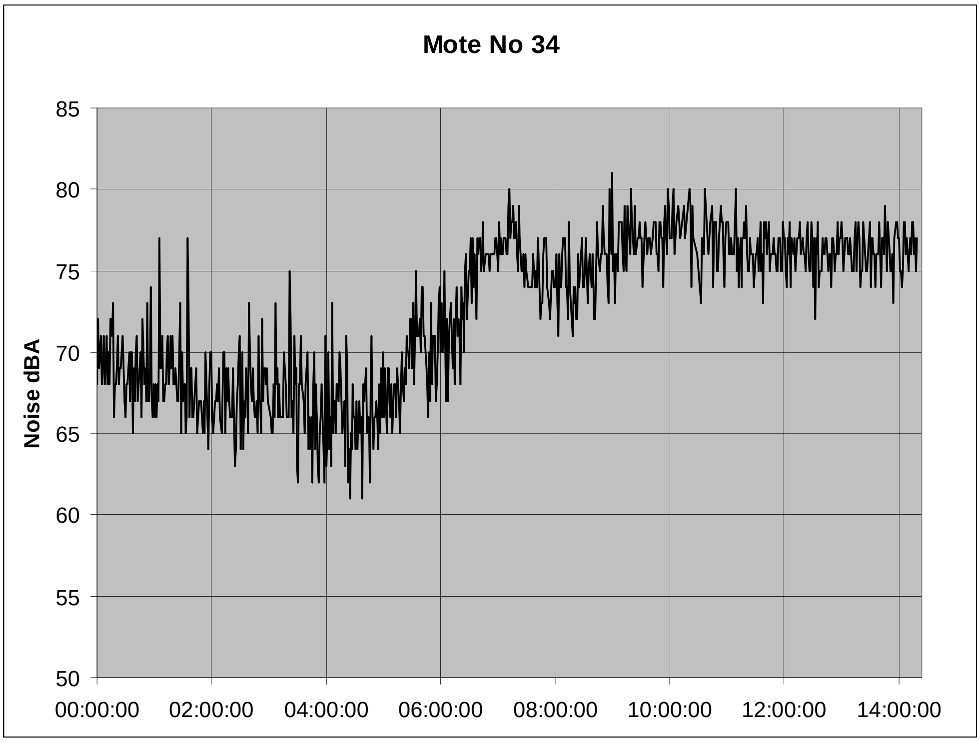


**Figure 8d: Midnight to 2pm data on Noise levels (dBA) from Mote #34**

## 4 Contribution to the ITS Field

This paper has summarised the research currently undertaken at Newcastle University to investigate the use of wireless sensor networks for road to vehicle communications applications. Considering the wide range of potential uses of these sensors in the transport domain, this is probably the most challenging environment for mobile ad-hoc networks.

However, the incorporation of part infrastructure, part mobile based network with fixed points (wireless devices fitted to street-side infrastructure) will broaden the capabilities of such future wireless systems (where investment in the intelligent infrastructure seems appropriate). The business model in the ITS community to invest in such a technology may come when these devices become smaller and cheaper as they are predicted to do over the next 5 years and indeed eventually become pervasive in nature as is envisaged by the 'smartdust concept'.

The projects have already shown that motes are a flexible new technology that can offer dynamic solutions to meet complex traffic scenarios and innovative demand management strategies. Prototypes have been evaluated using frequency bands around the 800-900MHz, 2.45GHz and 5.8-5.9GHz using communication protocols including IEEE 802.11x (WiFi) and IEEE 802.15.4 (Zigbee).

The pervasive nature of the technology enables vehicles to be 'always connected' to the infrastructure in the same way that home broadband users enjoy 'always-on' Internet access thus opening up the scope for an intelligent, configurable ITS infrastructure that will be available for a range of services to support travel and travellers. Thus road users will perceive direct benefits from the introduction of the technology thereby easing user acceptance. The costs of building and maintaining the infrastructure could be amortised over many such services delivered by third-party providers.

Research to deliver this concept of connected mobile devices and infrastructure leads to the opportunity to consider realistically for the first time a fully connected Intelligent Transport System for the future. Recently, the Office of Science and Technology published the findings of the Foresight Intelligent Infrastructure Study (IIS) [7], [8] which investigated how technology may evolve over the next 50 years to deliver a robust, sustainable and safe transport infrastructure in the future. Among the many recommendations and predictions on how the technology may deliver more intelligence into infrastructural systems was the view that pervasive wireless systems will have a significant future role in transport.

Concurrently, the use of radio frequency identification (RFID) for transport applications has begun to emerge as a key technology, particularly for use in the freight and logistics sector for tracking containers, pallets, individual products, for car-parking, ticketing and possibly for future road user charging. However Foresight recognised that RFID is just the starting point for a raft of more exciting possibilities with future wireless mobile ad-hoc networks and smartdust, with much more capability and 'intelligence' than current RFID and thus moving towards a more 'all-seeing, all-knowing' environment.

Research is currently focused on filling in the knowledge and technology gaps in pervasive, mobile ad-hoc wireless systems for a range of transport applications. Mobile wireless systems are beginning to be proven as a future tool that will enable the joining up of vehicles, individuals and infrastructure into a single 'connected' intelligent infrastructure system. Embedding this technology in infrastructure – such as environmental sensors in lampposts, embedded in vehicles and infrastructure, in goods, and even connecting individuals through their PDAs, mobile phones, or even bespoke wearable wireless interfaces (PANs – Personal Area Networks) – offer potential for a more all-seeing, all knowing ITS infrastructure. If for example, vehicles are continually in wireless communication with the infrastructure, new paradigms for traffic monitoring and control could be considered, road space allocated more efficiently and incidents dealt with in an optimum way. If vulnerable users have such wireless devices, the infrastructure could warn vehicles to slow down and the drivers to be more vigilant – indeed wireless devices attached to children could for example warn drivers that children are playing out on the street, just around the corner and to reduce speed now. Such devices could help with security and safety of individuals, be used on airline boarding cards and other tickets, and even be used to verify HOV (high occupancy vehicles) or blue badge entitlement. When such a system is also connected to say, a vehicle's CAN-bus, then information on driving style, strange driving behaviour (say where there is a badly maintained stretch of road or object in the road, could be detected from the CAN data – allowing mitigating and maintenance actions to be automatically triggered).

Many of these devices can carry payloads such as sensors, and the idea of monitoring pollution with these devices in a pervasive way is beginning to be researched in the MESSAGE project. Moreover with 'extreme' sensor design, wireless pollution sensors could be fitted in engine manifolds and exhaust pipes to allow the actual pollution generated by a vehicle to be measured and maybe adjustments to driving style or engine management systems can be advised or made to mitigate some of the pollution effects (early prototypes are being developed at the university at the moment). If future 'carbon allowances' are to be considered in the connected car, the pollution the car generates will also need to be measured and monitored – as proposed in the Smart Market Protocols project where auction and trading-based carbon allowances have been considered.

Wireless PANs on individuals through PDAs, mobile phones, or dedicated devices (such as motes integrated into jewellery – a research project currently in its early stages at Newcastle University) enable individuals to be connected and interact with the infrastructure. This thrust of research will finally provide the missing link in delivering the vision of future pervasive information delivery, whereby context specific and bespoke traveller information can be delivered to the individual on the move, through embedded screens in infrastructure, on mobile devices and for example on 'terminator' glasses where one is able to display traveller information on the lens of specially adapted spectacles (seen as particularly beneficial for mobility impaired users who are unable to interact readily with mobile phones and PDAs or other ICT systems). Indoor localisation systems based on wearable smartdust allow tracking of users within buildings providing a link between the concept of the connected vehicle and the connected person whereby pervasive, bespoke information delivery may have a role in influencing travel behaviour and travel choices and hopefully could help affect a modal shift towards public transport, particularly if the cost and carbon costs of the alternatives can be readily compared. . Research within the university is currently underway looking at novel indoor localization solutions [11].

Significant research is required to fully realise the potential of such wireless systems, not just on the transport application side, but challenges to reduce the size of these devices from 'smart-lumps' to 'smartdust' is critical as size, cost and power consumption of these devices will dictate whether the devices will become pervasive in the transport domain. This requires detailed work on antennae design, an investigation as to which is the most appropriate communications frequency, 802.11x, the influence of CALM (a range of connected communications standards) [16], WiFi and probably the most important challenge being battery power requirements (using power scavenging or other techniques). Also important are the issue of privacy and data protection in a potentially all-seeing, all-knowing connected world, which raises the question of how much information we want, need and what level of intrusion are we willing to bear.

This section has attempted to provide a glimpse of what wireless ITS may deliver to the transport sector in the near future. We have the opportunity to bring these technologies to bear to help meet the challenges of congestion, logistics, climate change and sustainability, as eloquently outlined recently in the recent Stern Review [20] and Eddington Report [9] in the UK.

## 5 Summary

The paper has provided an overview of the wireless systems research currently underway at Newcastle University. Here both technical and application specific research is on-going to investigate the potential applications and use of such systems in future transport applications.

More specifically, the MESSAGE project is developing a multi-sensor mote for deployment at the roadside and in the mobile environment (in vehicles, bikes and carried by travellers) to enable a new paradigm of pervasive environmental sensing. Whereby a large number of motes can potentially be deployed in an area to obtain a detailed view on the environmental pollution in that area in real time. Initial tests with both the wireless network, the motes and the sensors themselves all suggest that this approach may well be feasible for future wide are sensing.

It is recognised that these low cost sensor packages will never provide the same level of sensing accuracy as the traditional AQM (Air Quality Monitoring) stations that local authorities currently deploy. However one must consider how accuracy in sensing can be traded off against the pervasive sensing data available from the deployment of hundreds of low-cost sensors, providing an area-wide real-time view of an area. The success of the project may well be the development of new approaches to traffic and demand management based upon real-time and predictive environmental data. Trials later this year in Gateshead and next year in Leicester will be the first stages in the process of testing this hypothesis.

Finally the paper suggested how future intelligent infrastructure and embedded wireless systems could soon deliver a 'connected world' where vehicles, infrastructure and people are in constant communication, guided by intelligent 'travel' agents to make the best and optimal use of the transport networks and to make the best informed and intelligent use of the travel options available to them. It is likely that environmental considerations may be a significant parameter in these choices, hence the importance of projects such as MESSAGE and its sister project FootLITE which is looking at eco-driving research.

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