A Public Transport Bus as a Flexible Physical Mobile Smart Environment Sensing Platform for the IoT

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***Abstract*—In this paper we present the requirements, design and pre-deployment testing of a transportation bus as a Mobile Enterprise Sensor Bus (M-ESB) service in China that supports two main requirements: to monitor the urban physical environment, and to monitor road conditions. Although, several such projects have been proposed previously, integrating both environment and road condition monitoring and using a data exchange interface to feed a data cloud computing system, is a novel approach. We present the architecture for M-ESB and in addition propose a new management model for the bus company to act as a Virtual Mobile Service Operator. Pre-deployment testing was undertaken to validate our system**

***Keywords*— Internet of Things, air quality monitoring, road condition detection**

I. INTRODUCTIO

Public Transport (PT) buses are the most widely used and affordable transport vehicle in many urban and rural regions, globally. The trend is that cities and their transport are getting smarter [1], where smart simply means that a device is active, digital, networked, can operate to some extent autonomously, is reconfigurable and has local control of the resources it needs such as energy and data storage [2]. Three basic design patterns for smart devices and services are proposed: smart devices (including smart mobiles), smart environments (embedded with smart devices) and smart interaction between multiple devices [2]. Thus, a road vehicle acts as both a complex smart mobile device and as a smart environment supporting smart interaction between the multiple devices embedded in it. The operational vehicle data can be streamed in real-time via a wide-area GSM network or uploaded periodically via a vehicle to infrastructure (V2I) network via local area networks at bus stops and stations, as part of a wider system called an Intelligent Transport System (ITS).

The focus of smart vehicle development in the past has mostly been on better control and sensing of the vehicle and sharing this data with remote diagnostic services. More recently over the last decade, researchers have investigated whether or not PT buses can also be used to form a wider area physical mobile sensor bus that as it moves over road surfaces and through physical environment spaces, can be used to monitor the environment. For example, buses could monitor the state of the road network and air quality.

Air pollution is related to the urban population, thus people living in a large city such as London, Beijing or Mumbai are likely to be exposed to more air pollution than people living in smaller cities [3]. As there is also a strong link between bad air-quality and breathing related illnesses [4], it becomes important to monitor air quality, to check how well clean air policies are being adhered. Bad air quality also incurs an economic cost. It is estimated that the total economic value of the atmosphere was to be at least between 100 and 1000 time the Gross World Product [5].

When respect to road condition detection, different sensors (such as magneto-resistive transducer, piezoelectric transducer, speedometer et al.) can be deployed roadside or in vehicles or on travellers to provide transportation-environment-related information, i.e. traffic flow, vehicle speed etc. Hence, this d information can be used to inform a traveller so that he or she can avoid a heavily congested road that is more likely to also be highly polluted, and to choose a more lightly congested traffic route instead.

In terms of air quality monitoring, according to how and where environment sensors are deployed, systems can be divided into fixed, versus mobile or vehicle-mounted ones, respectively. Environment sensors, i.e. for CO, NO and NO_2, temperature, humidity, illumination, UV radiation, wind direction, wind speed, air pressure, and altitude tend to be deployed as fixed sensors [6]. These can be linked to geospatial related information to enable targeted air pollution monitoring and forecasting services.

However, due to the limited coverage induced by static sensors, some researchers have deployed mobile sensors embedded in private cars, taxis or buses to collect data for road conditions and traffic detection and for air quality monitoring. There are several advantages in using a smart hybrid mobile environment sensing design over a fixed smart environment sensor design. First, such mobile sensors can be used to sense environment data over a larger area - this tends to be less expensive to implement and maintain. Secondly, expensive sensors are not left unattended, fixed into specific environment locations, but rather are housed in a vehicle that protects them.

Thirdly, flexibility and scalability is important in designing such multi-use service infrastructures [7], e.g., additional sensors and buses can be added to increase coverage. Sensor maintenance costs are reduced because the maintenance work can be carried out in bus stations, instead of sending technicians in to the field to different fixed sensor sites. A suitable choice of bus lines can produce a detailed map of the pollution of a city, obtaining data from areas, which are less feasible to access, compared to using fixed sensor deployments.

We report the research and development of what we term a Mobile Enterprise Sensor Bus (M-ESB) for the Internet of Things, where these three smart design patterns, smart devices, smart environments and smart interaction, are combined. The M-ESB acts as a smart mobile environment that is embedded with multiple sensors to sense the physical environment and make it location-aware [8]. It uploads sensing data via an on-board sensor access node or gateway with wide-area wireless network access to a remote data storage centre for post-processing. Moreover, sensors are normally deployed by a private infrastructure provider such as a company or government administration department, which otherwise monopolises the use of the collected data. If others, i.e., other companies or government administration departments, want to acquire some related information, they need to deploy their own sensors and build their own sensor network, leading to a higher cost that may be redundant because others may need to deploy sensors in the same positions or mobile vehicles, to collect similar information. The information collected by different systems and organizations using heterogeneous sensors and communication infrastructures is more challenging to integrate to analyse for events of interest, e.g. one company may deploy a camera for excess vehicle speed detection, while another deploys ground sensor coils to detect vehicle weight and traffic volume on the road.

In order to reduce the deployment and operational costs for competing and overlapping mobile environment sensor systems, we are researching and developing a public transport bus as a mobile smart environment, where different sensors can be deployed to promote a new more flexibly horizontally integrated service market-place model [9] to drive new environment business and services. The service providers of the environment data, i.e., the bus company, will pay for the installation and maintenance of the sensors. In return, the bus company will get a financial incentive through selling data via a data sharing interface to those who want to buy the data for further analysis, Data as a Service or DaaS, e.g., searching for evidence of how well clean air quality policies are being adhered to, or for data mining. They can also provide Software as a Service (SaaS) to allow data users to use data processing services that can be easily customised by end data users.

The main contributions of this paper are as follows:

(1) We analyse and specify the design requirements and goals for both air and road condition monitoring using M-ESB.

(2) We present the architectural design for M-ESB that includes a multi-sensor data acquisition and sharing interface for a mobile sensor grid and router that feeds into a remote data cloud.

(3) We propose a new mobile service management model for a public bus company to act as a Virtual Mobile Service Operator.

(4) We propose a fault-tolerant on-board data gathering network through deploying two embedded gateways and through scheduling the operational state of redundant sensors.

The remainder of this paper is organized as follows. A critical analysis of related work is undertaken to highlight the best practice and limitations in Section II. Next, the requirements, design, and implementation for the smart bus, M-ESB are given in section III. Following this, the pre-deployment testing is described in section IV. Finally, the discussion, conclusions and further work are presented in section V.

II. RELATED WORK

There are several types of motivation to instrument a bus (vehicle) to enable it to communicate with remote data centres and servers: to monitor the urban physical environment and to monitor the road condition for transport. The main motivation is air quality monitoring and road traffic condition monitoring in urban physical environments. Each of these is analysed in turn.

A. *Monitoring Air Quality in Urban Physical Environments*

An air monitoring study was executed on a school bus to highlight that long time exposition to polluted air could cause respiratory illnesses to children [10]. Hereafter, more static wireless sensor networks have been widely adopted in air pollution monitoring [11], most of which consist of a few expensive, bulky, stationary sensor nodes. 22 air pollution-monitoring stations have been deployed in Beijing covering a 50×50km area [12]. However, due to the pollution monitoring facilities are few and far between. The limited monitoring coverage, namely, 113km2/per station, restricts the accuracy of the monitoring.

An important design issue is to select the data transmission method for the on-board sensor data - this depends on the application requirements for delayed-writes versus on-demand data transfer. If time-critical analysis is needed, data cannot be cached on the bus for a later upload to a data centre, instead on demand data exchange is needed. There are two main on-demand communication designs, use a mobile GSM router for WAN exchange versus using intermediate network notes accessed via a LAN. The use packet storage and forwarding between intermediate vehicles has the benefit that it can decrease the data exchange costs for the on-board mobile sensor system. An air pollution monitoring sensor network using an Opportunistic Mobile Sensor Network (OMSN) via V2V communications between PT buses was proposed in Singapore [13]. A CO_2 monitoring system [14] and multi-pollutant sensing system [15] were proposed and accessed through a Disruption Tolerant Network (DTN). Disruption may occur because of the limits of wireless radio range, sparsity of mobile nodes, energy resources, attack, and noise. Other researchers resorted to use taxis to transmit the monitored data [16].

When respect to V2I communication of mobile sensor data, different wireless links, such as Wi-Fi, cellular network (GSM/GPRS), are normally adopted. Another mobile environmental sensing system included spectroscopic UV sensors and adopted Wi-Fi and GPRS routers mounted on vehicles or carried by pedestrians to transmit data [17]. Multi-geo related monitored data was transmitted via a GPRS array in Sharjah, United Arab Emirates [18]. The OpenSense project combined community sensing with on-board hybrid sensor network on PT buses or fixed places including heterogeneous and private/public owned sensors in Switzerland [19].

[20] displayed the monitored data, ozone, CO, and NO_2 gathered by an on-board 8051-based microcontroller as a sensor map on a car. [21] utilised data mining for the monitored data gathered from a peer-to-peer network formed by mobile buses combined with static sensor nodes. [22] proposed a cloud-based real-time CO pollution monitoring system to handle hybrid data from an onboard data gathering network on public transportation combining with data from personal sensing devices, which consists of mobile air quality sensors and the use of smart phone as mobile data routers.

B. Monitoring Road and Traffic Conditions

Several different systems have been designed to monitor road traffic and surface conditions on roads. Many PT buses and private vehicles are equipped with dedicated SatNav devices or can use SatNav applications on mobile phones embedded with GPS, to log vehicle positions with respect to time [23]. Vehicle speed can be derived from GPS position changes and used to derive further indicators of traffic flow and congestion, e.g., a GPS based road traffic congestion detection algorithm was proposed as an ITS application by [24]. Using GPS data and a Geographical Information System (GIS), speed, distance travelled, and the journey time taken by PT buses, can be derived by [25]. Vehicle flow data from traffic sensors embedded in PT buses on urban roads can be transmitted via an on-board mobile gateway [26].

PT Passengers are also interested in accessing timely information concerning when a bus reaches a bus-stop on-route or whether or not it is delayed. [27] processed GPS latitude and longitude information from embedded position sensors on PT buses to provide passengers with accurate automated reports about bus arrival at bus-stops. In another schema, IEEE 802.15.4 based beacons were added at bus-stops and onboard PT buses, through calculating the position in relation to a roadside beacon; it could be determined when a bus enters bus-stop if it was on-time or delayed [28]. A real-time passenger information system using inbuilt PT GPS supplemented by citizen sensing using mobile phones has been trialled [29]. If GPS was available on PT buses, this location data was used. However, if no inbuilt GPS was available on buses, which was common in some PT services in poor rural areas in undeveloped countries, mobile phone sensing was initiated by a smartphone app called GetThere by PT passengers. Real-time passenger information, e.g. timetable and route descriptions, can be transmitted to data management centres using mobile phones as mobile routers [30].

For road surface anomaly detection, accelerator sensors in mobile phones can be used to detect potholes in roads. In Pothole Patrol, the collected information from on-board vibration and GPS sensors on participating vehicles was transmitted through an opportunistic Wi-Fi___33 connection. If the Wi-Fi connection is not available, information is transmitted via a cellular network to a data centre [31].

C. Discussion

Table 1 Comparison of how the surveyed PT bus systems monitor air quality and traffic and exchange data for remote data storage (where temp= temperature; we use '✓' if a property is supported, 'X' if it is not)

Ref.	Air Quality Sensor	Traffic Sensor	Road Surface Sensor	Gate way	WAN Link	On-board network	Data Management
[14]	CO2	GPS	X	X	V2V Wi-Fi DTN	Wired	GIS
[15]	CO_2, temp., humidity	GPS	X	X	Wi-Fi	Wired in a box	Web-service
[17]	spectroscopic UV sensor	GPS	X	✓	Wi-Fi or GPRS	Net with XScale CPU	Data base
[18]	CO, NO_2, SO_2	GPS	X	X	GPRS	Sensing units	server
[19]	CO, CO2, NO_2	GPS	X	X	GPRS	mobile sensing units	Data-base
[20]	ozone, CO, NO_2	GPS	X	X	Bluetooth USB cable	Wired/ Bluetooth + microcontroller	Data -base
[21]	SO_2, NO_X, O_3,	X	X	✓	Wi-Fi ZigBee	Sensor unit	Data mining
[22]	CO,	GPS	X	X	GSM	Mobile sensing	Cloud Server
[24]	X	GPS	X	X	X	X	Data -base
[25]	X	GPS	X	X	X	X	Data-base
[26]	X	X	X	✓	DSRC	Ad hoc	Data-base
[27]	X	GPS	X	X	X	X	Embedded CPU
[28]	X	X	X	X	WSN	Not clear	Data-base
[30]	X	GPS	X	X	X	Mobile phone sensing	Data -base
[31]	X	GPS	accelerometer	X	Wi-Fi-GSM	Wireless link to embed-ed CPU	Data base

The analysis of the above research work is summarised in Table 1. There are several dimensions to the analysis: Air quality sensing, traffic sensing, road surface sensing, data gateway use between on board sensors and remote data centre, type of on-board sensor network used and data management.

Most air pollution and road condition detection applications use ZigBee [21], Bluetooth [20], or wired communication links to transmit the sensor data to an on-board embedded processor, i.e. a XScale processor or a microcontroller, to do data pre-processing [17],[20]. Alternatively, sensor data can be transmitted via a fixed or mobile gateway to access the IP backbone network to a remote database for data storage [17], [26], [21]. Sensor data exchange can be classified as delay-tolerant versus time-critical or real-time respectively. Delay-tolerant data is transmitted via a DTN [14], [15] through a V2V network or opportunistic network [26] to an intermediary converged data node, including using another vehicle. Then this converged data is transmitted to a remote database via V2I link, i.e. a WLAN link Wi-Fi, etc. In contrast, real-time data is transmitted to a remote data centre usually via a cellular network directly [15], [17], [18], [19] and [22].

III. Requirements, design and implementation

A. *Requirements Analysis*

a) M-ESB supports two main sets of requirements, sensor data collection, and business requirements. The on-board sensors form an information gathering network to monitor the physical environment. The data generated in the data gathering network is a mix of low-bit-rate information e.g. temperature, humidity, light, GPS and high-bit-rate such as video information inside and outside the bus. Note that although a very wide range of sensors can be supported, an iterative approach is adopted to start with a simpler core system and then to extend this later.

b) For low-bit-rate data, such as temperature, humidity, and light, IEEE 802.15.4 is adopted as the physical layer and data link layer protocol for the WPAN. Compared to other short-distance wireless access methods in network layer, e.g. Bluetooth and 6LoWPAN, ZigBee has a more compacted system with only 28Kb system memory, compared to 250Kb system memory for Bluetooth. Besides, ZigBee has a simpler protocol stack compared to 6LoWPAN, in 6LoWPAN, there is an additional adaptation layer implemented to allow common sensors based on 802.15.4 protocol access to IPv6 backbone network. Hence, ZigBee is adopted as the on-board data gathering network for data communication.

c) To achieve more reliable communication for high bit-rate data from a video camera, wired communication is adopted. An on-board embedded gateway is utilised to transfer data from the local onboard sensors over an external communication link at an access point, e.g., a Wi-Fi access point at a bus station or a cellular base station. The gateway can also support a delayed-write upload when the bus is out of range of specific local network access points. Considering the fault tolerance of the onboard network, there are two embedded gateways onboard, one is the main gateway for data transmission and the other is an assistant gateway, which is normally in its sleep mode in case the main gateway fails.

d) As the bus travel around cities, reliable and versatile sensing data related to environment and road conditions can be converged at the data management unit, or data control centre, where a data sharing interface for data exchange is made available to those who wish to use it for further data mining and who are willing to pay. Thus, a bus becomes a Mobile Enterprise Sensor Bus (M-ESB) for the bus company. Using such M-ESBs, the bus company becomes a Virtual Network Operator (VNO), which provides ICT services with the help of the infrastructure network deployed by telecom operators.

B. *Design and Implementation Overview*

The surveyed systems tend to deploy special sensor systems for air-quality monitoring or for traffic flow and road surface monitoring separately. In contrast, we propose a novel M-ESB schema combining both air quality monitoring and traffic flow detection together in an extensible way. In our approach, different sensors are hosted by the bus company to provide an open marketplace for a multitude of end users to access. Buses with onboard sensors act as a super mobile sensing node. Through the mobility of PT buses, the sensor coverage is enlarged. Sensor data from buses on different routes can be combined in time and space to form a citywide sensor grid that shares data with a remote database. Sensor data can be dispatched to paid users, thus, the bus company can become a new operator, namely, a virtual operator. Consequently, the buses with sensors onboard become a mobile enterprise bus.

As the sensing, storage and computing resource of a single sensor node is limited, different types of sensing nodes onboard can form an Internet of Vehicles network with distributed computing and communication resources for the exchange, processing and storage of the sensor data via a gateway [32]. Thus, the gateway acts as a unified sensor array that supports multiple interfaces for different types of monitoring data. Then, for a generic M-ESB with unified sensor array, we can define it as a Super Sensing Node (SSN). Every SSN transmits its sensing data to the database as an independent mobile node. As buses move, multi-mode data from multi nodes are converged at the data sharing interface. Thus, the discrete, distributed resources possessed by different mobile SSNs cooperate at the database to form a Grid, which is defined as a Mobile Sensing Grid (MSG) for sensing information collection, which can feed a remote data cloud for use in multiple application services.

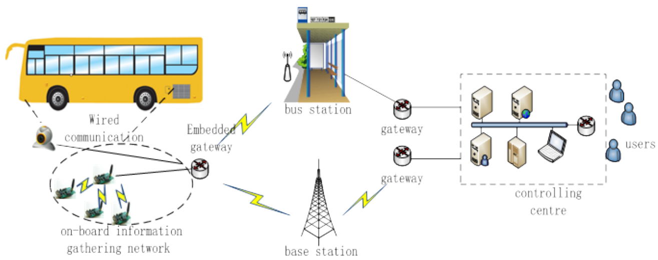

Fig.1 Overview of the M-ESB

An M-ESB consists of the following sub-systems: an onboard information-gathering network (comprising sensors, senor local area network and sensor access node including memory to store the data and a CPU), embedded gateways to upload the on-board sensor data to access the IP backbone network, and a remote data-centre (see Fig.1). The on-board bus subsystem contains two main functional modules: the environmental surveillance module and a gateway for data submission to a bus station (Wi-Fi) or 3G/4G base station. If there is a free Wi-Fi hotpot in the bus station, the sensing data is transmitted to IP backbone network via a Wi-Fi link. However, if the data is sensitive to time, as well as the Wi-Fi link is not accessible, data is transmitted to the backbone network via cellular network with a charge. The environmental surveillance module here initially contains temperature, humidity, light, GPS and camera sensors that collect the urban environmental data along the bus line when buses run in the city.

A Texas Instruments CC2530 at 2.4 GHz with a ZigBee PRO protocol stack is deployed on-board to gather the environmental sensor data. For location and velocity detection, we adopt a NEO-6M-0-001 GPS model. A Vimicro ZC0301 unit is selected for picture or video capture, which has an adjustable compression ratio, supporting JPEG standard image compression and 15 fps VGA video display without DRAM. Fig.2 gives the hardware module for CC2530 (on the left), GPS module (middle) and camera (on the right).

Each of main components of the M-ESB is discussed in turn.

C. *On-board Sensor System*

1) The on-board bus subsystem contains two main functional modules: the environmental surveillance module and a gateway for data submission to a bus station (Wi-Fi) or 3G/4G base station. If there is a free WiFi hotpot in the bus station, the sensing data is transmitted to an IP backbone network via WiFi link. However, if the data is time-sensitive and the WiFi link is not accessible, data is transmitted to backbone network via a cellular network. The environmental surveillance module here initially contains temperature, humidity, light, GPS and camera sensors which collect the urban environmental data along the bus line.

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a.

Fig. 2 Overview of CC2530 (left), GPS (middle) and camera (right)

Embedded system gateways (main and assistant gateway) are used to provide external access to roadside communication units at the bus stop or via a cellular base station. In Fig.3, A CortexA8 microcontroller is used to implement a gateway, which contains LCD panel, wireless WAN communication model, flash, DDR and other interfaces for wireless or wired communication access onboard. GPS module (middle) and camera are connected to the gateway by a wired (USB) communication interface.

Multiple CC2530 modules form a ZigBee network. In a generic ZigBee network, devices are divided into Full Functional Devices (FFD) with full ZigBee protocol stack that is adopted as coordinator and router in the network. Reduced Functional Devices (RFD) with part ZigBee protocol is used as an end device. Different devices can form star, tree and mesh topology for data collection. In our proposed network, since monitoring data from the environment is changing slowly, in order to save energy, simpler data routing based on a star topology is used. Such a star-topology network is formed by a FFD as the coordinator centre with RFD-typed sensors for environment monitoring as end devices deployed on buses.

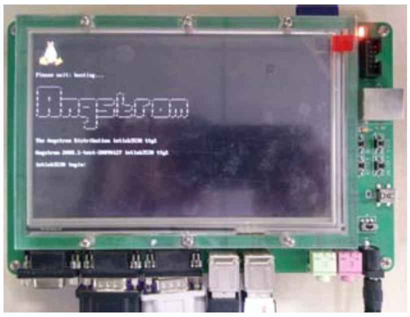

Fig.3 Overview of the embedded system gateway

Under normal operations, every two or three end nodes are partitioned into a sub network, which is scheduled to be active periodically every five minutes to execute a sensor task data exchange asynchronously, with a coordinator within its active sub network. Ifs an end sensor node becomes paralysed due to energy exhaustion, the coordinator can activate another mirrored sleeping peer node for data sensing. Hence, the star topology is fault-tolerant, for the WSN is used. The coordinator of a star network is deployed within the middle of the bus, and the end devices are deployed uniformly within the bus.

When devices are powered on, they scan the wireless channel. The FFD device confirms itself as the coordinator, and selects a PAN ID for the star network as well as sets a short address for itself, e.g., 0X0000. Then, other RFD devices access the star network with a short address in the PAN and set the coordinator as their destination node. Moreover, the star network is extensible to attach new end devices. The frame structure used in our onboard information gathering network is defined as shown in Fig.4: @Inf head (1byte)+@Inf len (1byte)+@Inf type (1 byte)+@dst addr (2 byte)+@node ID (2byte)+@Inf (n byte)+@check sum (1byte). The @Inf head fields fill in the beginning of the information, and the value of @Inf len indicates the total length of the @Inf type. The @dst addr field fills in the address of the coordinator, and the value of @node ID that indicates its ID in the network. The @Inf fields fill in the sensing information (up to 60 bytes). Finally, the @check sum field stores Cyclic Redundant Check (CRC) code. According to the ZigBee standard. @Inf fields support two frame types: a Control frame, and an Information frame. The Control frame consists of REQ_connect, ACK_connect, REQ_retran, ACK_retran, and ACK_information, which are responsible for the control commands of connect request/acknowledge, retransmission request/acknowledge and transmitted information acknowledge, correspondingly. The Information frames are used to store the environment sensing data, which currently stores the following information: temperature, humidity, the position data from GPS and light. This can be extended to support other sensing information from environment.

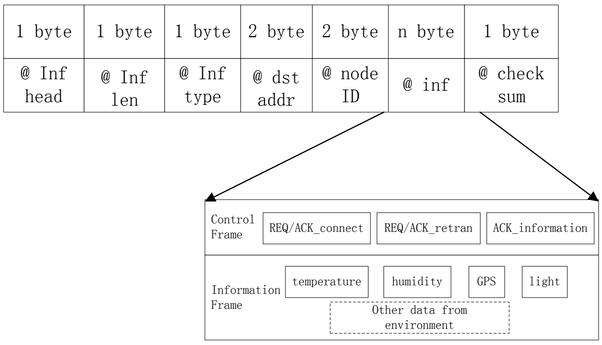

Fig.4 Data format of on-board information gathering network

D. *Data Transmission and Management by The Remote Data Center*

When a coordinator aggregates data from the end devices, it connects with the embedded gateway, in which the low-bit data is initially stored and pre-processed. This is then transmitted via the Wi-Fi module (802.11b) in the gateway to the bus-station as the bus enters bus station at the end of the line, where data is uploaded to data centre. For high-bit video or picture data from ZC0301, which is already compressed according, this is transmitted via the gateway to a GSM base station. Although for low-bit data, the bus could be designed to upload it in real-time using the 3G module via mobile phone network, our system currently does not do this because no real-time decisions are taken based upon these data. So instead, data is uploaded via a Wi-Fi link at the bus station to reduce the data transmission cost.

	COLUMN_NAME	DATA_TYPE	NULLABLE	DATA_DEFAULT	COLUMN_ID	COMMENTS
1	BUSID	VARCHAR2(20 BYTE)	No	(null)	1	(null)
2	BUSLINE	VARCHAR2(20 BYTE)	No	(null)	2	(null)
3	BUSTEM	VARCHAR2(20 BYTE)	No	(null)	3	(null)
4	BUSHUMIDITY	VARCHAR2(20 BYTE)	No	(null)	4	(null)
5	BUSSPEED	VARCHAR2(20 BYTE)	No	(null)	5	(null)
6	LATITUDE	VARCHAR2(20 BYTE)	Yes	(null)	6	(null)
7	LONGITUDE	VARCHAR2(20 BYTE)	Yes	(null)	7	(null)
8	BUSDATE	VARCHAR2(20 BYTE)	Yes	(null)	8	(null)
9	BUSTIME	VARCHAR2(20 BYTE)	Yes	(null)	9	(null)
10	BUSLIGHT	VARCHAR2(20 BYTE)	Yes	(null)	10	(null)

Fig.5 Data field in data sharing interface

In the data centre, we design a data sharing interface based on Java and Oracle, a common Database Management System (DBMS). In the data layer, we define data field, which is illustrated in Fig. 6, to form a data chart. The data attribute are divided into BUS ID, BUSLINE, BUSTEM, BUSHUMIDITY, BUSSPEED, LATITUDE, LONGITUDE, BUSDATE, BUSTIME, BUSLIGHT. BUSID denotes the license plate number of the tested M-ESB. BUSLINE is the operation line of the M-ESB. BUSTEM, BUSHUMIDITY, BUSSPEED, LATITUDE, LONGITUDE, BUSDATE, BUSTIME, BUSLIGHT are temperature, humidity, speed, latitude, longitude, tested data, tested time and illumination data for the tested M-ESB respectively. All data types are varchar which has a length of 20 bytes without comments. Data related to latitude, longitude, busdate, bustime and buslight can be nullable. In addition, we define reserved data field for future test data (see Fig.6).

COLUMN_NAME	DATA_TYPE	NULLABLE	DATA_DEFAULT	COLUMN_ID	COMMENTS
GAS	VARCHAR2(20 BYTE)	Yes	(null)		(null)

Fig.6 Reserved data field for future tested data in DBMS

E. *Data Interface and Web Application*

Users can access sensor data from the DBMS via a data sharing interface based upon a Model-View-Controller (MVC) design. In the Model layer, a .NET database connection class is used to access the initial data from the Oracle database. Then, in the Controller layer, some internal functions are called to convert data to XML. In the View layer, the XML data format is displayed using ASP.net. In order to display the on-road traffic flow, we used a Javascript API to call a 3rd party GIS, Baidu[1]. Via this API, the XML formatted geo information can be displayed on a Web page.

Further, we define a congestion index C_I to denote the traffic flow as follows,

$$C_I = \frac{T - T_0}{T_0} = \frac{L/V - L/V_0}{L/V_0} = \frac{V_0 - V}{V}\Bigg|_{V \notin \sum_V \mathbf{1}_{\{V \in trafficlights \cup V \in busstop\}}} \quad (1)$$

Where L indicates the length of the tested journey between two bus stop and traffic lights, which is independent from C_I. V is the average vehicle speed at a certain position on route, allowing for stops traffic lights and bus-stop on L. V_0 is the maximum free-flow vehicle speed, defined as the maximum legal speed on road L. C_I relates to vehicle speed. The higher C_I is, the lower the actual vehicle speed becomes, which represents congestion and a worsening traffic condition. In contrast, a lower C_I denotes a relative higher actual vehicle speed, which denotes better traffic conditions.

IV. PRE-DEPLOYMENT TESTING

A. *The Test of Hardware in Data Gathering Network Aboard*

Some tests are executed to inspect the operational conditions of the camera, the operation of the ZigBee network and GPS in the onboard data gathering network. The embedded gateway uses a multi-task Linux OS, which has a Linux kernel to store camera data. Fig. 7 shows the raw data from ZigBee and GPS module at the serial interface of the gateway, which includes temperature, light, humidity information from ZigBee module and latitude, longitude, date, speed values from the GPS model.

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[1] A Chinese GIS and custom map view generator, see http://www.baidu.com/

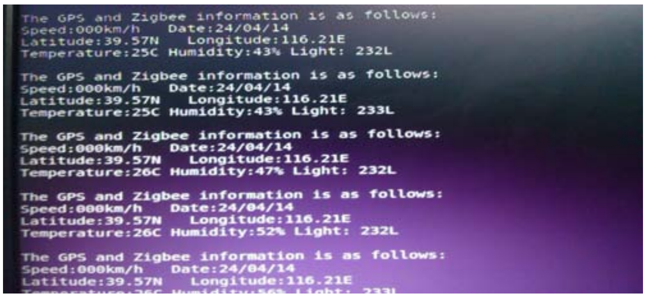


Fig.7 The raw data at the serial interface of embedded gateway

B. The Test in Data Sharing Interface

Some pre-deployment tests have been executed on the No. 498 bus route in Beijing to check the acquisition of environmental data during the normal bus operation. Fig 8, demonstrates that the on-board video camera works. Fig. 9 demonstrates that the environmental information is displayed on the Web interface that uses GIS to display a bus route and some key points of interest. The blue line denotes the real operational line of a bus, and the red marks represent the different test positions on the road. When a user clicks a red mark, more detailed information appears on the GIS map view, e.g., pertaining to a congestion index.

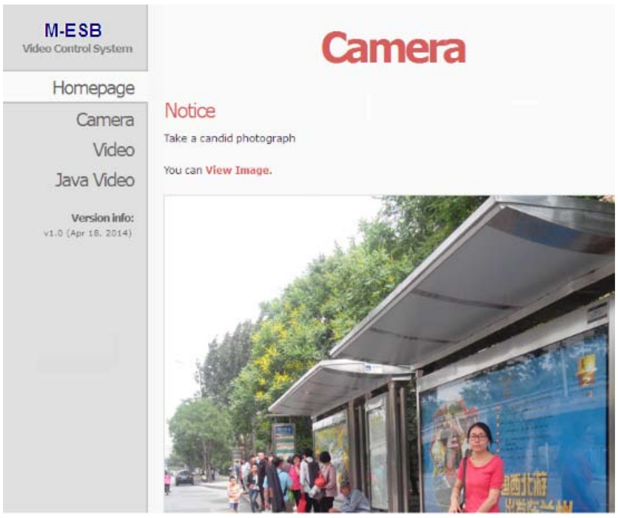
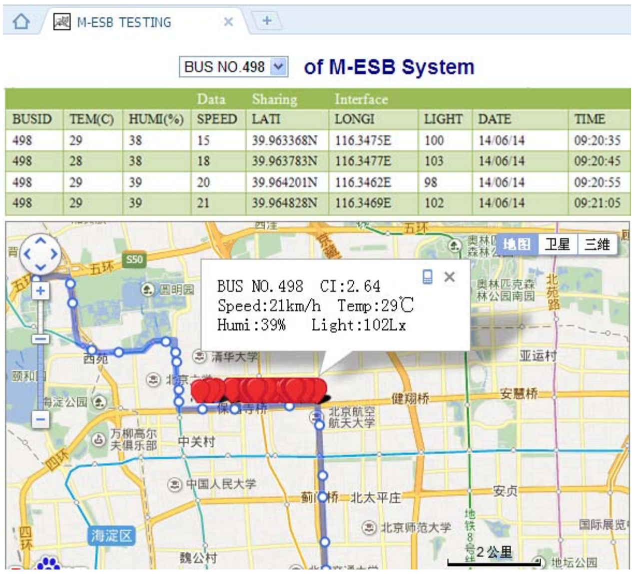


Fig.8 The Web application for camera



BUSID	TEM(C)	HUMI(%)	SPEED	LATI	LONGI	LIGHT	DATE	TIME
498	29	38	15	39.963368N	116.3475E	100	14/06/14	09:20:35
498	28	38	18	39.963783N	116.3477E	103	14/06/14	09:20:45
498	29	39	20	39.964201N	116.3462E	98	14/06/14	09:20:55
498	29	39	21	39.964828N	116.3469E	102	14/06/14	09:21:05

Fig.9 The data sharing interface for pre-deployment test

V. CONCLUSIONS AND FURTHER WORK

Increasing urbanisation is often accompanied by an increasing number of vehicles on the road. These may cause problems such as decreasing air quality, road-surface damage and congestion. The conventional approach to urban monitoring is to use fixed roadside sensors but these provide limited coverage. It can be costly to scale-up such a design to monitor a whole city in detail. We propose to use public transport buses as a Mobile Enterprise Sensor Bus (M-ESB), which can realise both environment monitoring and road condition detection using on aboard Sensor Networks (SNs). The requirements, design and pre-deployment testing for M-ESB are discussed. Moreover, we provide a new market-place management mode for the bus company. The bus company can deploy sensors on PT buses, and host the data sharing interface to sell sensing data to those who interested to do further data processing and become a new service provider, namely, a virtual service operator. To monitor more aspects of the environment and the individual bus operation, additional air quality monitoring sensors will be deployed on buses in the future. It is also important to develop a design for customer data privacy, security and trust in such marketplaces [33].

ACKNOWLEDGMENT

This work is supported by Research and Application of Key Technologies in Smart Grid Park Energy Management and Optimization for Smart City.

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