Evolution of Ubiquitous Computing with Sensor Networks in Urban Environments

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ABSTRACT

A significant increase in real world event monitoring capability with wireless sensor networks will lead to a further evolution of ubiquitous computing. This paper describes this evolution, leading to humans being connected to the real world via computers without awareness. We address an ad hoc communication paradigm, a data-centric approach, and a middleware's task, to understand the ultimate goal of this new world. We also briefly explain our upcoming new traffic monitoring project in the city of Cambridge.

EMERGENCE OF WIRELESS SENSOR NETWORKS

The evolution of cyber space started from mainframe computers and moved to PCs. Then Internet glues computers for information sharing. Later, ubiquitous computing named as the third wave by Mark Weiser [5]. A rapid increase of event monitoring capability by wireless devices brought a further evolution in ubiquitous computing. This new paradigm is about networked microprocessors embedded in everyday objects, surrounding us, talking to each other over wireless links. There will be small nodes with sensing and wireless communication capabilities and they are able to organize themselves flexibly into a network for data collection and delivery [1]. Wireless Sensor Networks (WSNs), which are composed of wireless sensor nodes distributed in the environment, include various sensors (e.g., cameras as vision sensors, microphones as audio sensors, and temperature sensors). Each node is equipped with a wireless communication transceiver, sensor, power supply unit, machine controllers, and microcontrollers on a MEMS (Micro Electro Mechanical System) chip which are only several millimeters square.

AD HOC COMMUNICATIONS

These WSNs can cover a large space by integrating data from many sensors, and can gather diverse and precise information on the environment. Moreover, the integration of smart WSNs with a bigger network such as the Internet increases the coverage area and application domain of the ad hoc network. Based on such a technological vision, new types of applications will rely on ad hoc connections between nearby nodes to establish multi-hop dynamic routes in order to propagate data and messages between out-of-range nodes. Sensors could be attached to any object, which may move around, or be placed stationally. Furthermore sensors could be attached to the human body creating Personal Area Network (PAN). The communication among objects, humans, and computers happens at home, at an office, on a street, at the train station, in a car, in a restaurant, or in other places at any time. Fig.1 shows application spaces for ubiquitous computing with WSNs. Ubiquitous Computing opens communications over tiny sensor networks through Internet scale peer-to-peer networks. WSNs on local ad hoc communications may connect occasionally to the Internet via gateway or mobile nodes, which collect the data from an isolated ad hoc network, or delay/connection tolerant networks [2], where the ad hoc network itself could be created based on the social contacts.

UbiComp'05 September 10-11, 2005, Tokyo, Japan

DATA CENTRIC APPROACH

WSNs revolutionize information gathering and processing both in urban environments and inhospitable terrain. Sensors can detect atomic pieces of information, and the information gathered from different devices will be analyzed and provide data that has never been obtained before without these technologies. Combining regional sensed data from the different locations spawns further information. Localized algorithms, in which simple local node behavior achieves a desired global object, may be necessary for sensor network coordination. Modeling such system is attempted by studying biological systems, distributed robotics, and amorphous computing.

An important issue is that the sensed data should be filtered, correlated, and managed at the right time and place when they flow over heterogeneous network environments. It is not easy to provide reliable and useful data among the massive information from WSNs. Mining new information from sensed data is one thing, and deploying how to obtain the desirable information over WSNs is another thing. Combining both approaches will enhance data quality, including users intentions such as receiving data, providing data and passing data. Imagine an urban scenery such at a train station, and your phone obtains a high volume unwanted data. At the same time, data should be managed as openly as possible.

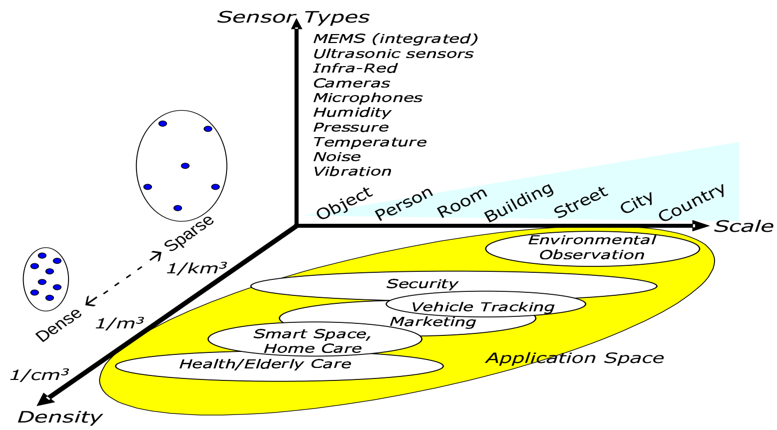

Figure 1: Application Spaces for Ubiquitous Computing with WSNs

MIDDLEWARE'S TASK

The middleware in sensor networks can be defined as software that provides data aggregation and management mechanisms, adapting to the target applications need, where data are collected from sensor networks. This functionality must be well integrated within the scheme of ubiquitous computing. The middleware should offer an open platform for users to seamlessly utilize various resources in physically interacting environments, unlike the traditional closed network setting for specific applications. One of the important issues here is to support an unambiguous event correlation mechanism over time and space in heterogeneous network environments, where middleware should take an active role [6]. The trend of system architecture to support such platforms is towards service broker grids based on service management. When designing the middleware for sensor networks, heterogeneity of information over global distributed systems must be considered. The sensed information by the devices is aggregated and combined into higher-level information or knowledge.

ULTIMATE GOAL OF UBIQUITOUS COMPUTING

What is the ultimate goal of ubiquitous computing? Humans develop the earth in a technology centric way that is bringing pollution, global warming, and extinction of animals. We need to better understand the nature and environments, so that our lives improve. What surface of the roads will prevent raising the temperature in tropical countries? What will prevent freezing the road surface to avoid traffic accidents in snow countries? How much is a green belt in a city necessary to produce sufficient oxygen ecologically and how to improve airplane path control systems with increasing possible paths and at the same time avoiding collisions. Now, we have new sets of data that will give entirely new information to improve our lives on earth.

When smart space is created in an urban society, our life style will get impacts. Communications among family could expand via instant messaging when you are in remote locations that may tie the relation tighter. Business will be processed over the wireless networks that may produce extra time for better life. Early discovery of health problems via sensed data from the body may save many lives.

We have many issues to address for realizing such an ubiquitous society. From social aspects, with use of sensed data, issues will be who can trace whom, who can obtain data, who controls the technology and use (user, government, or device owner), monitoring the society vs. risk control, and protection of privacy and security. Who should be controlled of cyber meetings by ubiquitous devices could be of political interest. From cultural aspects, different degrees of ubiquitousness may be considered such as SMS (Short Message Service) vs. email, or adhocracy vs. deep thinkers. Also how we establish a common ground for the innovation in infrastructure of the society and how to set rules over network use should be addressed. From the economic aspect, real-time sensing will become a new business, and an industry will form a new infrastructure for micro payments of new business.

TRANSPORT MONITORING PROJECT

An upcoming project *Transport Information Monitoring Environment* (TIME) at the University of Cambridge is a framework for research, application development and deployment for transport monitoring in the city of Cambridge in United Kingdom.

Cambridge lies approximately 50 miles (80 km) north-northeast of London and is surrounded by a number of smaller towns and villages. The population is around 125,000 (including 23,000 students). Because of its rapid growth since the 20th century, Cambridge has a congested road network. Several major roads intersect at Cambridge (see Fig.2). The M11 motorway from east London terminates here. The A14 road east-west trunk route skirts the northern edge of the city. This is a major freight route connecting the port on the east coast with the Midlands, North Wales, the west coast and Ireland. The A14 road is considered by many local people to be dangerous, and unnecessarily congested. This is particularly true of the section between Huntingdon and Cambridge, where the east-west traffic is merged with the A1 road to M11 motorway north-south traffic on just a 2-lane dual carriageway. The A10 road is a former Roman road from north London. The city has a ring road about 2km in diameter, inside which there are traffic restrictions intended to improve conditions for pedestrians, cyclists and bus users and to reduce congestion. It has a good park and ride bus service encouraging motorists to park near the city's edge.

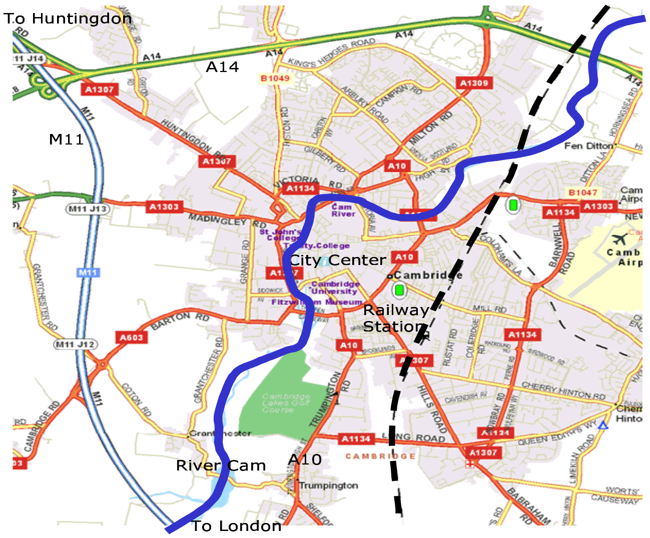

Figure 2: City of Cambridge and Surroundings

The Cambridge railway station was built in 1845 and it has direct rail links to stations in London. The important UK rail hub of Peterborough is also within reach of Cambridge. The railway service connecting Cambridge and Oxford, known as the Varsity Line, was discontinued in 1968. Thus, if you take a train to travel between these cities, you have to travel to London and change the train unless driving a car or taking a shuttle bus.

As a university town lying on fairly flat ground and with traffic congestion, Cambridge has a large number of cyclists. Many residents also prefer cycling to driving in the narrow, busy streets, giving the city the highest level of cycle use in the UK. There are also many beautiful cycle routes in the countryside surrounding Cambridge. According to the 2001 census, 25 percent of residents traveled to work by cycle. The main organization campaigning to improve conditions for cyclists in Cambridge is Cambridge Cycling Campaign. The city will also soon be linked to the growing National Cycle Network.

Cambridge is best known for the University of Cambridge with 31 colleges. In Fig.3, colleges in the city center are marked with black circles. As an English city, there are many pubs in Cambridge. By 1749 the number had risen to 156 inns and pubs, serving a population of 10,000 and in 2002, the 112 pubs serve a population of around 125,000. Fig.4 shows the location of pubs in Cambridge, which covers most major roads within the city and shows that pub culture deeply influences the people's life.

Road congestion in the UK costs in the order of 20bn GBP per annum, and many business investment decisions are believed to be influenced by the quality of transport. The purpose of TIME project is to monitor, distribute and process traffic information so that it will provide a substantial and significant increase in transport efficiency. This would not only improve business efficiency but would also have a profound effect on pollution control and source of UK emissions of carbon dioxide. But lack of a car can be socially excluding, and good public transport is essential for social integration. Timely information is key to the to the acceptance and wider use of public transport.

It is therefore vital that we improve the performance of the UK's transport networks while balancing the need for economic efficiency, social equity and environmental quality. Cambridge has a diverse economy including a high tech cluster of companies, variety of transport links and closeness to London. Existing transport information systems, for example to gather data on traffic density on the M25 motorway (ring road surrounding city of London), to provide information display at the bus stop, to control traffic signals to ease congestion or to give a fast route to emergency vehicles, to display the number of empty spaces in car parks, are single theme and vertically integrated projects that as yet do not fully exploit the potential of fixed and wireless networks.

Thus, one purpose of the TIME project is to provide a common, open interface. The interface will be robust to changes in the underlying technology that allows the gathered data to be shared in a controlled way. An important aspect is to ensure that the privacy of individuals is not violated. It offers programmable interface so that users are able to tailor the data for their needs. At the same time, the interface should be standardized for cooperating with other transport systems.

The ultimate aim of the TIME project is to improve the understanding of transport network performance in the long-term by developing novel traffic data monitoring, management and modeling systems. Initially, TIME will use the city of Cambridge as a compact and convenient test bed, where it has severe congestion problems. Transport providers and other industry partners with interests in the transport sector are being actively sought for collaboration in defining and implementing such projects.

Our upcoming project *Event Architecture and Context Management* (TIME-EACM) project [3] is a central plank of the TIME project. The goal of the TIME-EACM project is to investigate, design and implement a secure but open interface to support the controlled sharing of monitored data from any form of transport.

Concrete outcomes of the TIME-EACM project will be a middleware that hides low-level sensor aggregation from applications, integration of high-level context models with query support, and an evaluation of this support based on prototype, but real world, applications that fully exploit the architecture. Issues include economics of information, building incentives to information sharing, extracting useful information from sensed data, queries (e.g., what is happening) and how the environment can adjust to what it senses. This will be a challenging realization of ubiquitous computing in urban environments. There are many possible applications, including congestion detection and projection, car park status, bus arrival time displays, free taxi location, and support for emergency services. The middleware developed for the project will be made available as open source software as it has potentially wide application for other traffic monitoring projects and for a range of event-driven applications where sensors have been used to monitor state of environments.

The TIME project is in an early stage, and we have a mountain of issues in front of us. What sensors should be used? How should sensed data be interpreted? There are already many sensors deployed in the city at such as CCTV, Car Parks, Bus GPS, Traffic signals, Pedestrian crossing, and Highway. Fig.3 shows the location of CCTV cameras in the city center, which covers most part of the central area. Besides the existing sensors, what will be the best

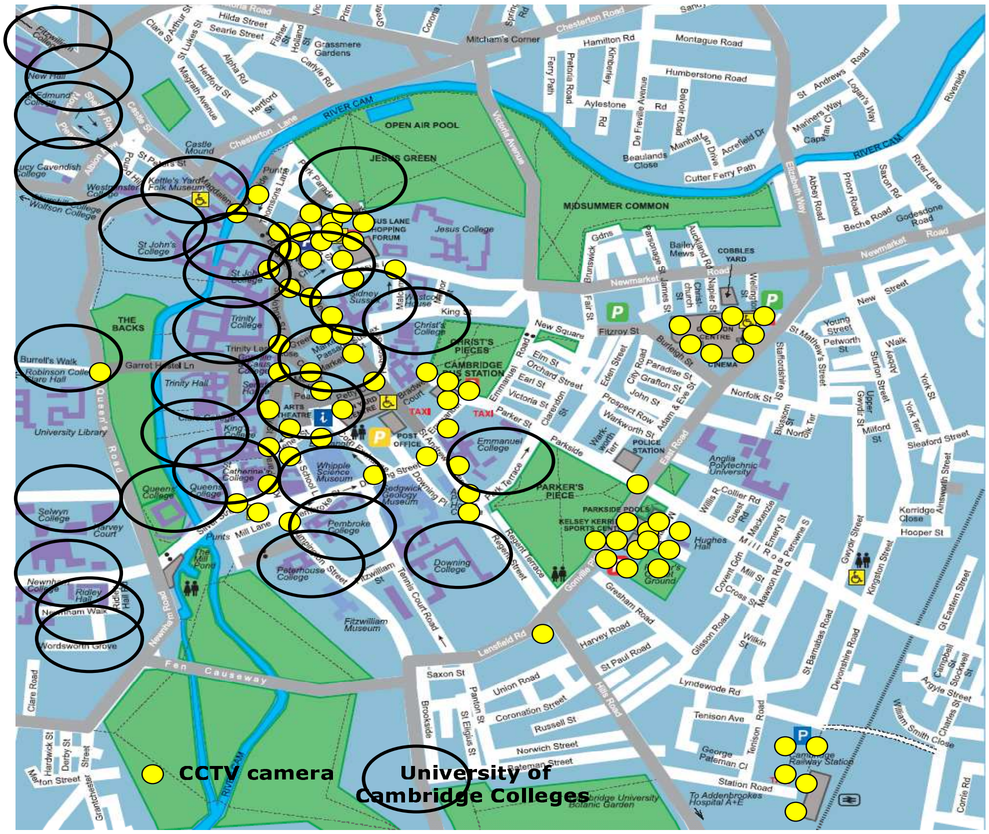

Figure 3: CCTV camera locations in City center Area of Cambridge

way to coordinate new sensors such as GPS on vehicles, RF tags, video cameras, and audio facilities? For data collection, what communication systems (e.g., GPRS, SMS, WiFi) should be deployed? Data collection could be done by forming an opportunistic network such as [2] or preconstructed mesh [4]. How should road-to-vehicle and inter-vehicle wireless communication be addressed? One significant observation in Fig.3 is that University of Cambridge colleges cover most of the central area. Each college has its own computer network infrastructure under the university's control and many of them provide wireless network access. This setting must be used for creating urban spaces in Cambridge. Another observation Fig.4 is that pubs are at almost every block, and people are there building social networks. Most of them carry mobile phones using SMS for connecting people outside of the pub. Many pubs facilitate digital satellite TVs for football matches that can provide high speed Internet access, too. An important issue here is that supply of transportation information and demand, quality of life, safety and environmental impact as well as legal issue and privacy concerns have to be balanced.

CONCLUSION AND FUTURE WORK

We have presented design issues for building ubiquitous computing with sensor network technology, where sensor data provide various range of information. We described our upcoming traffic monitoring project and an initial approach to address complex relationship between ubiquitous systems, urban space and society.

Acknowledgment. This research is funded by EPSRC (Engineering and Physical Sciences Research Council) under grant GR/557303. I would like to thank Prof. Jean Bacon (University of Cambridge) for valuable suggestions.

Bio. Eiko Yoneki is a PhD candidate in the Computer Laboratory at the University of Cambridge, UK. Her research interests are distributed computing systems over mobile/wireless networks, including event-based middleware, delay/connection tolerant ad hoc networking, and event correlation. She has received a postgraduate diploma in Computer Science from the University of Cambridge in 2002. Previously, she has spent several years with IBM (USA, Japan, Italy and UK) working on various networking products. She is a member of ACM and IEEE Computer Society. (http://www.cl.cam.ac.uk/users/ey204/)

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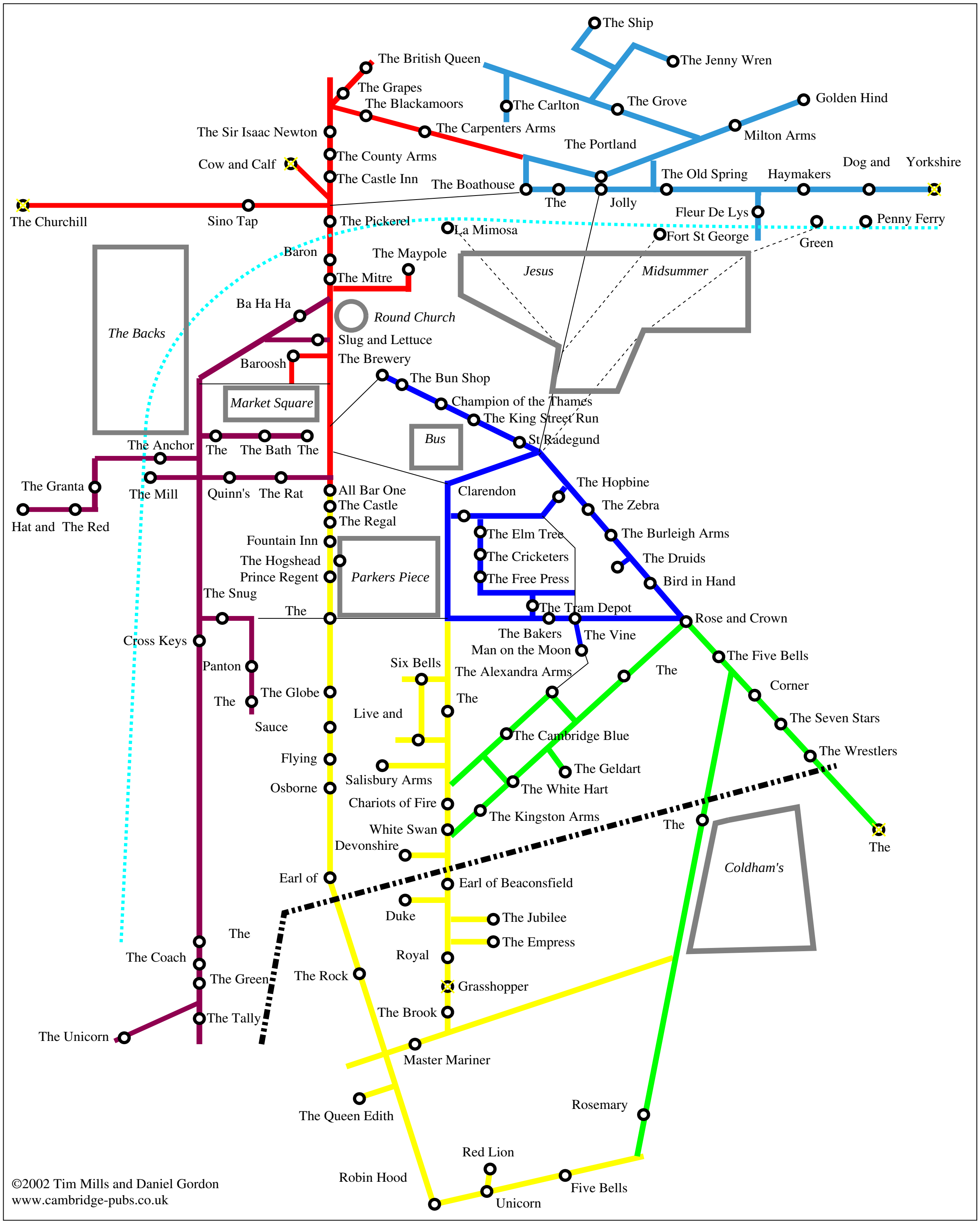

Figure 4: Pubs in Cambridge (from Tim Mills and Daniel Gordon at the University of Cambridge)