How Ubiquitous Can We Get?

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Abstract. Proliferation of hardwired and wireless networks across the globe and into the solar system is accelerating. Complexly overlapping machine-to-machine, human-to-human and machine-to-human relations are now normal, not exceptional. Traditional boundaries are becoming fuzzy, traditional infrastructure is becoming obsolete, planning for future technologies increasingly difficult. Although the trend toward a ubiquitously networked world is clear, the technological convergence appears to be exceeding expectations to such a degree that it seems mankind is seriously underprepared. To assist orientation in this historically unprecedented revolution, this paper presents a brief history of digital history, a survey of contemporary developments, a look at the practical implications for the near future and a relatively casual consideration of the more debatable not-so-near future.

Keywords: Ubiquitous Computing, Machine-to-Machine Communication, Internet of Things

1 Introduction

In pre-technological times, the practical experience of daily life was a continuum with little change. But the slow cumulative effect of technological advancement led finally to the industrial revolution, with increasingly rapid change in daily life. In the latter half of the 19th century, this trend gave rise to the literary genre that is now called “science fiction.” One modern science fiction view of the future is characterized by a ubiquitous network of digital devices. That future has not yet arrived but its design and implementation are progressing well.

The concept of “ubiquitous computing” was created by Mark D. Weiser in 1988 [1]. At that time, networking and related digital technology were still in their infancy. The Macintosh II had been available since March, 1987. Microsoft released Windows 2.0 in December, 1987. Weiser is quoted, “Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives.” During a talk, Weiser outlined a set of principles describing ubiquitous computing. He said, “The purpose of a computer is to help you do something else; the best computer is a quiet, invisible servant; the more you can do by intuition the smarter you are; the computer should extend your unconscious; Technology should create calm.” Weiser also said, “This is different from PDA's, dynabooks or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere.”

The observation that the number of transistors in integrated circuits doubles approximately every two years was noted first in 1965 by Intel co-founder Gordon E. Moore. Now called “Moore’s law,” it is still holding approximately true as shown in Fig. 1 [2] and is commonly cited with regard to long-term targets for research and development [3]. Contemporary levels of miniaturization, computational power and digital ubiquity would have shocked the people of Weiser’s era. Moreover, the rate of such evolution, significantly independent of but not unrelated to the number of transistors on a chip, seems to be increasing. Certainly the number of scientists and engineers and the amount of international competition/cooperation dedicated to such evolution are greater than ever, trends which show every sign of continuation. Accordingly, this paper suggests that technological evolution over the next several decades will result in levels and varieties of digital ubiquity more surprising to us than current levels would be to Weiser’s era. Weiser said: “For thirty years most interface design, and most computer design, has been headed down the path of the "dramatic" machine. Its highest ideal is to make a computer so exciting, so wonderful, so interesting, that we never want to be without it. A less-traveled path I call the "invisible"; its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it. I believe that in the next twenty years the second path will come to dominate. But this will not be easy; very little of our current systems’ infrastructure will survive.” Although adapted to a prior period, Weiser’s general principles seem highly relevant to our present situation. Nevertheless, we feel Weiser strongly underrated the trend toward ubiquitous computing (ubicomp).

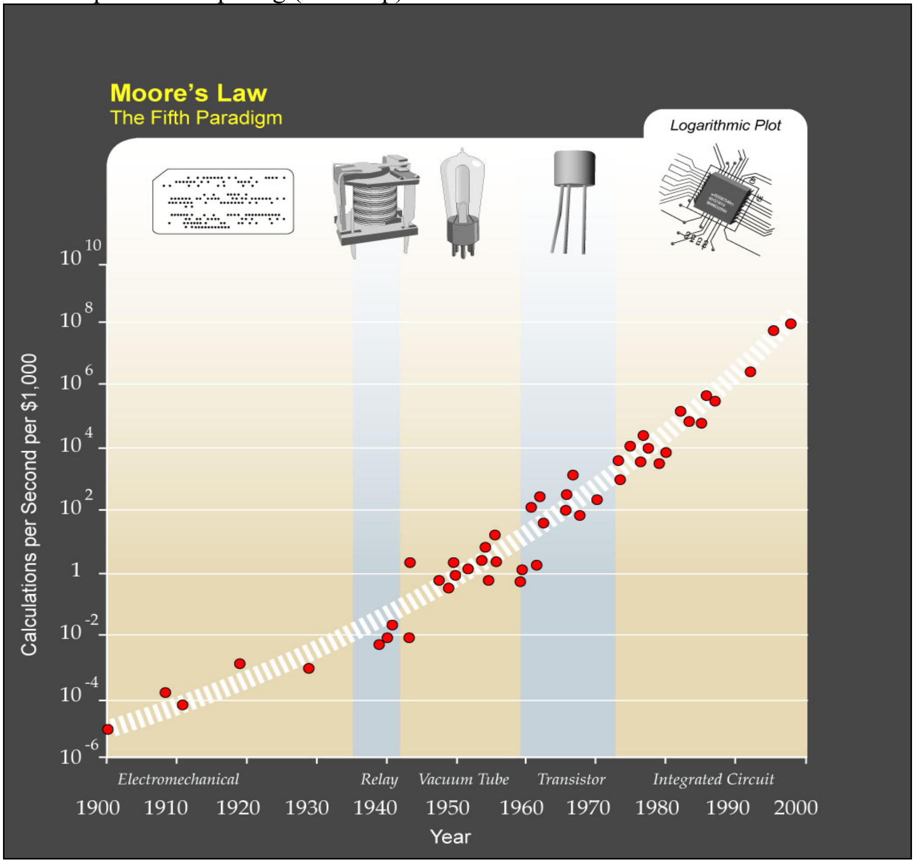

Fig. 1. The exponential trend of Moore's law continues to be a valid tool for tracking digital progress, but actual progress is supported by many collateral technologies, not merely transistor count.

2 Contemporary Development

Technology is not a single field but instead is an accumulated and interactive set of knowledge from many fields. The timeline of Fig. 2, which is a segment extracted from von Stackelberg timeline (http://www.datavis.ca/gallery/timelines.php), puts into temporally comparative perspective some of the major collateral technological trends since the practical employment of electricity.

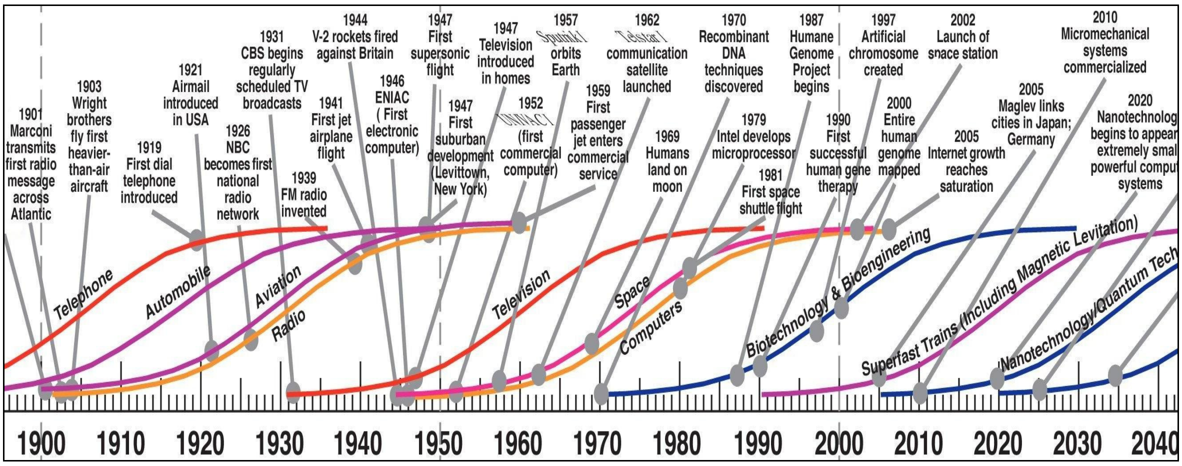

Fig. 2. A summary of recent collateral technological development.

It is reasonable to suppose that our earliest computational tool was the fingers or "digits," evidenced by modern legacy linguistic features such as "digital" computers and our base-10 counting system. Technology progressed and marks on paper supplanted counting stones. Calculating mechanisms were invented such as the abacus. Converging metallurgical, machining and conceptual technologies led to mechanical calculators such as the mid-17th century designs of Blaise Pascal. Charles Xavier Thomas created the first mass-produced mechanical calculator around 1820. Electrical relays and vacuum tubes replaced mechanical equivalents around World War II. There was no "first" computer but rather a cumulative convergence of diverse technologies. In 1951, the first mass produced computer, UNIVAC I (Universal Automatic Computer) appeared. Each cost more than $1 million ($8.5 million in 2011), used 5,200 vacuum tubes, consumed 125 kW of power and was capable of storing 1,000 words of 11 decimal digits plus sign (72-bit words). In 1947, it was observed that two gold point contacts applied to a germanium crystal could produce an output signal with power greater than the input. This is generally considered the first transistor, a design which evolved rapidly and soon replaced traditional electrical relays and vacuum tubes. Unlike earlier alternatives, the transistor required little power, was highly shock-resistant, lightweight and cheap to produce. Looked at historically, the marriage of the transistor to Univac led to contemporary desktop computing. The drive toward miniaturization, increased computational power and reduced power consumption continues. Desktop systems are being replaced by ever more powerful, diminutive and energy efficient portable devices. Where does it lead?

Before the desktop computer had become a common household item, converging technological advances had led to workstations arranged in a network around a central "super-Univac." Networking technology was dawning. Packet switched networks developed in the 1960s and 1970s, joining multiple separate networks into a network of networks. The first multi-networks interconnected local networks at different universities. By 1972, fifteen sites connected to the now-extinct ARPANET (Advanced Research Projects Agency Network, decommissioned in 1990). But in another corner of the technological arena, personal computers were arriving. At first, integration and development of the various collateral systems and technologies seemed no great task nor of great risk. However, the purring stray Internet kitten brought home and given a bowl of water and a box to sleep in grew almost overnight into a strange and formidable tiger that shows every sign of continued and rapid growth. Private and government-sponsored hackers are now capable of interrupting computer assisted surgery, disrupting the functions of factories, shutting down national power grids and causing many other issues of mass consequence. The social questions continue to multiply. The latest generation of cell phones and small mobile computers are now considered critical data nodes in the Internet. Even elementary texting is now being used to coordinate social pranks or civil disobedience. Web-connected phone-cams have become key links in international news networks. Meanwhile, the Internet continues to expand, driven by ever greater public demand.

Another seemingly simple and almost trivial technology developing collaterally with the Internet is radio frequency identification (RFID). RFID began as a form of resonator which retransmitted incident radio waves and was used in WWII-era identification friend-or-foe (IFF) transponders and covert listening systems. Currently, RFID devices are best known as the humble identification and anti-theft tags common in retail stores. Modern RFID [4] may be said to have begun in 1970 when Mario Cardullo patented a passive radio transponder with 16bit memory, powered by an interrogating signal. Cardullo suggested RF, sound or light as transmission media, with applications in automotive identification, electronic license plates, electronic manifests, performance monitoring, electronic check books, electronic credit cards, personnel identification, surveillance, medical identification and patient history.

Cardullo's suggested applications have proven highly prophetic since RFID is currently used in all those capacities and many more. RFID tags can be either passive or active. Passive RFID minimizes size, weight and cost by omitting an on-board power source, but progress in miniaturization and integration has seen development of a wide range of active RFID devices with on-board batteries. At present, the largest deployment of passive RFID is in the WalMart store chain, with perhaps 2800 retail stores and over 25,000 readers. The world's largest active RFID network is in use by the U.S. Department of Defense (DoD) and contains more than 7,500 read sites in 50 countries, tracking more than a quarter million shipments per week. It provides location, condition and security data via a mixed system of bar code, passive and active RFID, sensors, Global Positioning Systems (GPS) and Satellite Systems (SATCOMM) technologies.

The trend toward increasingly miniaturized and versatile RFIDs shows every sign of continuing. Implantable RFID devices were originally designed for animal tagging but are now being used for humans. Traditional RFIDs carried on a person are now being carried in an under-the-skin format. The Baja Beach Club in Barcelona, Spain, uses an implantable Verichip to identify their VIP customers and to pay for drinks. Currently, RFIDs are often integrated with sensors. Skin-mounted or implanted RFIDs with sensors to monitor body functions are already in use. As devices grow smaller and circuitry more versatile, it is not difficult to imagine a world where, for example, each single tooth filling has its own imbedded RFID device monitoring the status of both the filling and the tooth, with the data being immediately accessible by home computer or cell-phone. Extending this notion a little further allows us to see a future where each individual citizen contains a complex network of RFID devices, monitoring and even providing active feedback to organs in the body. Clearly, the distinctions between traditional machine-to-machine (M2M), machine-to-human (M2H) and human-to-human (H2H) boundaries are becoming increasingly blurred.

Clearly, our present world is changing faster than ever before, making even the savviest among us sometimes struggle to stay abreast of all the new gadgets, services and jargon. At this point, it is impossible to forecast which of the present alternatives will dominate and what new alternatives may appear. In general, however, it appears that the future will rely heavily of what we are presently calling “wireless sensor networks” (WSNs). WSNs involve significantly different issues than traditional wireless or wired networks because of their focus on sensor and actuator based interactions. They are becoming progressively more sophisticated and pervasive in both casual and critical technology. It is very common these days for many different devices in many different parts of a country to be monitored and controlled by a single server in a single city, which is in turn monitored and controlled by a single human in a different city via his home laptop or even his cellphone while he is on the go. The functional criticality and number of such network nodes are increasing rapidly. Likewise, the design challenges facing the world’s researchers are increasing.

In any case, the current trend toward increasing ubicomp is seen in the daily appearance of novel electronic devices which expand our networks and digital capacities beyond their prior limits. A recent example is the Airwriter glove, a new human-machine interface which allows typing without a keyboard. Released this year (2013) in Germany, the Airwriter [5] (Fig. 3) is an electronic glove that lets people write in mid air. In more conventional terms, this keyboardless system is capable of determining what is being written by monitoring the position of the user's hand. A computer interacts wirelessly with the glove, system capturing the relevant signals and translating them into text. A complex set of sensors attached to the glove displays the position of the hand in space and detects the movements of the fingers. The sensors also determine when the user is actually writing as opposed to merely moving his hand around normally. The current prototype system is reported to have an error rate of 11%. The present Airwriter system recognizes complete sentences written in capital letters and has a vocabulary of 8,000 words. Integration of a compact and perfected Airwriter with Google's new Glass viewer immediately leads to novel speculation regarding the next few the ubiquitously networked world.

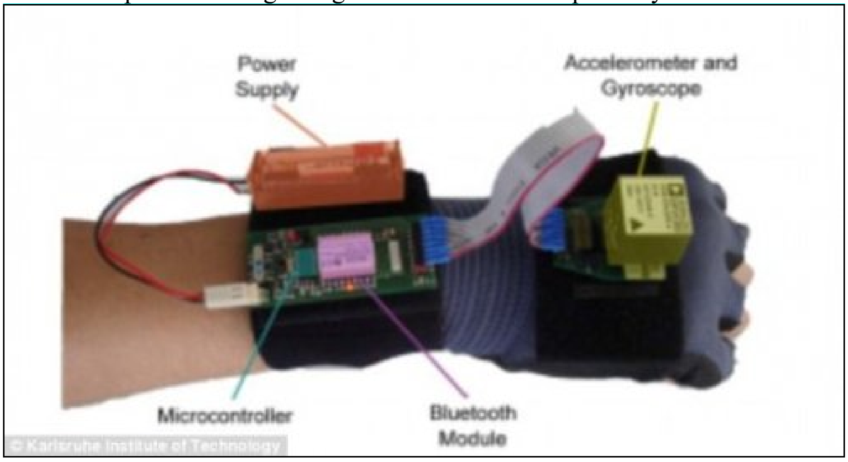

Fig. 3. The 2013 prototype Airwriter glove.

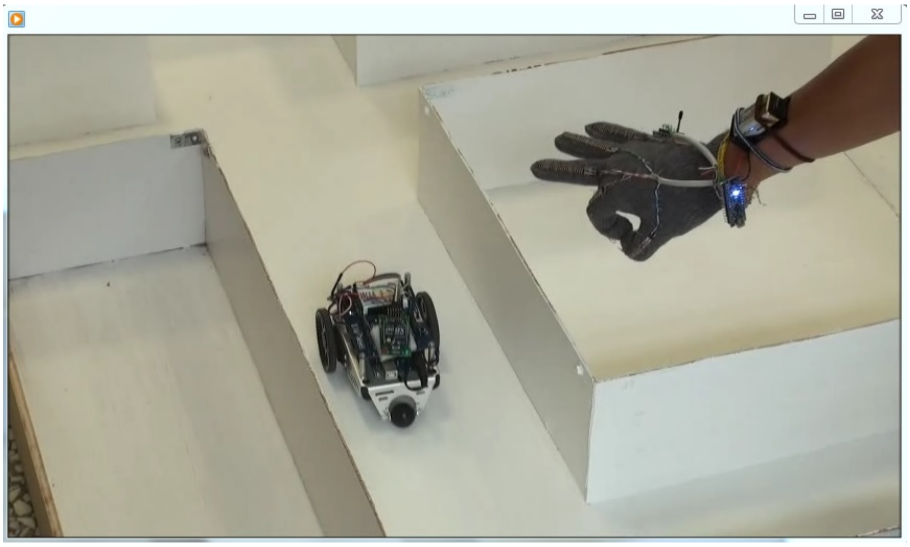

Fig. 4. Our prototype data glove controls an ABB vehicle with simple hand gestures, guiding the car through a large maze.

The Airwriter data glove's many sensors make the system a type of ubiquitous sensor networks (USN) application which offers potential as a wireless human-machine interface. With this notion in mind, some of our group have been testing data glove control of a small robotic car (Arduino BOE-BOT, ABB). Simple finger gestures direct the ABB vehicle to go forward, backward, turn left, turn right and stop. In what became a standard experiment, our group XBee-wirelessly directed an ABB car through a maze using only uncomplicated hand signs which the data glove's sensors identified and transmitted to the ABB vehicle (Fig. 4). Clearly, such experiments are only small steps in the development of higher forms of digital systems, with the net process leading to increasingly higher forms of ubicomp. Consumers are already anticipating sophisticated hands-off keyboardless control of many types of devices. There is no doubt that the data glove is one such option. Simultaneously, other contemporary research groups are experimenting with mental control of digital devices. The present and extensive research is yielding so many new possibilities that the specific technologies to be employed in the future remain unclear.

3 The Near Future

Designers of our present era are already laying the tentative foundations of what will presumably become an progressively sophisticated and deeply networked society. The ubiquitous sensor networks (USN) of Fig. 5 are a recent concept expected to provide a variety of advanced services in the near future. The specific forms of the future systems will change to suit the era, technological context and task. At the present, it is nominally clear that various networks will interact with the large variety of wireless sensor devices that will be found in smart furniture, smart walls, smart fish bowls, smart home security systems and within the smart systems which will monitor the ongoing biological functions of the consumer's children.

Source: ITU NGN-GSI Rapporteur Group Meeting " Draft Recommendation *Y.USN-reqts*, "Requirements for support of USN applications and services in NGN environment," (Geneva, 11-21 September 2007), available at: http://www.itu.int/md/T05-NGN.GSI-DOC-0266/en

Fig. 5. Contemporary relatively shallow thinking regarding USN near-future applications. The trend toward deep ubicomp is clear but the present view remains remarkably shortsighted.

This ongoing blurring of traditional digital boundaries can be exemplified by the fact that the short message service (SMS) has become an important transmission mechanism for M2M communication [6]. This may sound surprising since SMS is commonly identified with brief H2H cellphone messages, but the reality of a smart refrigerator texting a smart air conditioner or tweeting a smart garage door opener is already here. The reliability of SMS as a conduit of critical information is an ongoing issue, but SMS gateways connected by Signaling System 7 (SS7) now offer confirmed delivery, making SMS-based M2M a reasonable alternative for non-critical applications and boding well for the converging future.

The number of devices connected to the Internet has been predicted to reach 7 trillion by 2017, considerably more than the number of humans using the devices [7]. However, the speed of actual implementation in the context of the present troubled economy makes such issues difficult to predict. In any case, considerable current work is directed at making RFID tags smaller, cheaper and more versatile. RFID tags already can be invisible and applied by ink. Active RFID devices grow rapidly more sophisticated. At the same time, miniaturization and fabrication technologies improve. The convergence of these trends suggests a day not too far away when each piece of paper you use has its own recorded identity (accessible by Internet as to location and general physical condition, e.g. pristine, wet, torn, virtually destroyed but still in a trash can), each nail in a building, each brick in a wall, each organ in a human body, etc, has its own RFID tag. If/when that day arrives, it is easy to see that 7 trillion is far too small a number.

This type of thinking has given rise to the concept of the Internet of Things (IoT). The term IoT was first used in 1999 [8] during attempts to develop a global RFID-based item identification system to replace the UPC bar code. IoT was a logical concept for monitoring items like packing cases during shipment or clothing stock in a fashion boutique. However, the current actuality is strongly challenging the existing paradigms. Certainly the possibility of mounting RFID devices on/in pigs not only to monitor the pig's location and environmental temperature but also to warn of pending child birth goes beyond the earlier IoT concepts. The implantation of RFID sensors in the brain to monitor and possibly even prevent the onset of epileptic seizure presents unprecedented philosophical issues regarding "mind control" and the general image of man verses machine verses the general environment. Commercial charge-coupled devices (CCD) have already been wired into the brains of the blind to provide a degree of vision. Similar experiments have provided a degree of hearing. Other work has certainly proven the possibility of direct wireless control of digital devices by the brain. Even though it's early days yet on these technologies, researchers are already beginning to consider devices in the body which provide hands-free on-the-go cellphone service. The implications of such work are huge and only lightly surveyed. Our research group nevertheless expects the pending convergence of such technologies to be faster, more surprising, far more challenging and dramatically more useful than anticipated.

The impact of miniaturization in terms of digital ubiquity needs further consideration. Assuming reasonable pricing, the range of a device's potential applications increases as the device size declines. In 2009, researchers at Bristol University studied ant behavior by gluing RFID micro-transponders to live ants [4]. In 2010, Hitachi reported a record-small RFID chip of 0.05mm × 0.05mm, 1/64th the size of the previous mu-chip record holder. The dust-sized chips stored 38-digit numbers using 128-bit Read Only Memory (ROM), but antenna difficulties limited the read range to millimeters. Mobile ad hoc networking (MANET) has been suggested to overcome the transmission range issues of such diminutive devices. MANET coordinates transponder nodes so that each node not only captures and disseminates its own data but also works as a relay for other nodes. Routing techniques allow messages to hop from node to node until the destination is reached. Self-healing algorithms allow for route reconfiguration around broken or blocked paths. Such networks are typically quite reliable. If the number of nodes is large enough, there is normally more than one source/destination path, making a MANET of tiny short-range devices quite feasible.

An additional issue of micro and nano devices is power supply. One considered solution involves energy harvesting, i.e. using the device's background energy, e.g. solar power, thermal energy, wind energy, chemical gradients, wearer motion, ambient radio and television electromagnetic energy, building vibration, etc. Conveniently, ambient background energy is free. Practical miniaturized energy harvesting using micro-electromechanical system (MEMS) technology is well demonstrated [9]. Convergence of these technologies has already led to the concepts of "smart dust" and "smart specs." These are mm-scale autonomous devices forming massively distributed wireless sensor networks. Smart dust was introduced by the USA's Defense Advanced Research Projects Agency (DARPA). The Nano-electronics Research Centre at the University of Glasgow is part of a large international consortium developing smart specks. Smart dust motes have been demonstrated that include sensors, interfaces, power sources, digital control communications and processing circuitry within a few cubic millimeters [10]. Various self-assembly methods have been proposed. Commercial systems are already available. A web site at SPECKNET contains an extensive bibliography.

And the demand for further miniaturization continues unabated.

4 Conclusion

Research, miniaturization and innovation are making remarkable progress in electronics and a host of collateral technologies. These trends are expected to continue into the distant future. At the moment, electronic devices are moving from millimeter to micrometer levels, with nanometer levels presumably pending. The electronic invasion of the world and of the human body is well underway. The pace of technological progress has never been greater and seems to be accelerating. How ubiquitous can the networked world become? Or should we start to talk about the networked solar system, since our working network already extends to the limits of the furthest functioning communicating space probes. Returning to Mark Weiser's comments at the start of this paper regarding the transition from the traditional world to the world of ubiquitous computing, "... this will not be easy; very little of our current systems infrastructure will survive".

This is clearly a challenge to contemporary planners, who seem to be viewing the probable future with attitudes more suited to those of the Industrial Revolution.

In light of the ongoing technological developmental trends, we ask:

- How ubiquitous can we get?
- How ubiquitous do we want to get?
- Do we actually have any choice in the matter?

5 Acknowledgement

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