From "Cellphone" to "Remote control on life":
How wireless communications will change the way we live over the next 20 years[1]

William Webb[2], BEng, MBA, PhD, FIEE, SMIEEE, CEng

PA Consulting, Cambridge Technology Centre, Melbourn, Herts, SG8 6DP, United Kingdom

Abstract — **Wireless communications might be said to have "come of age", with the number of wireless phones in some countries surpassing the number of fixed phones, and wireless operators having much greater market value than fixed operators. At the same time, many new technologies are about to be introduced including third generation mobile, wireless LANs, BlueTooth-based personal area networks, high speed fixed wireless solutions and more. New services such as mobile access to the Internet, e-commerce from a mobile, video phones and others are being trialled and deployed. With all these developments, the direction that the future will take is not readily apparent. Based on detailed research this paper proposes a future based on the integration of multiple disparate networks.**

I. VISION OF COMMUNICATIONS IN 2020

It is the 21st May 2020. John Smith is asleep at home. Today he has to take a business trip from New York to San Francisco where he is going to make a presentation to a key customer. These trips are now much less frequent as John tends to make more use of video conferencing rather than attending in person, but this time the customer is sufficiently important that he wants to show this by doing things the "old-fashioned way". He will stay the night in San Francisco and fly back the following morning. John booked his flight using his personal communicator interlinked to his company's travel agent. The personal communicator has stored these details and advised John that he will have an early start that day. It has checked expected travel conditions and calculated that John will need to get up at 5.30am, however, early the following morning it will re-check traffic conditions, re-check the flight schedule and determine exactly when John needs to wake up.

At 5.20am the communicator utilizes its BlueTooth capabilities to communicate with the in-home network. It pre-warms the house and starts to prepare a breakfast for John. It confirms with John's preferred travel site the route that John will take and downloads this to the car, checking that the car has sufficient fuel and that its diagnostic systems have not detected any problems.

At 5.30am the communicator plays wake-up music that John has set as his preference until it hears John say "alarm off". It then presents John with his itinerary for the day. John gets ready to leave the house, drinks his coffee and then climbs into his car. The communicator starts up the car a little before the journey so that the interior is warm, opens the garage door as John climbs into the car and closes the garage door as John's car turns out of the drive. It locks all the doors in the house and confirms with the house control system that the house is secure.

John subscribes to a personal news service directly with a number of news agencies. His communicator visits these sites and retrieves his daily summaries. For playing back in the car, these are still in audio format, but if John finds any interesting he may say "retrieve video" for the video image to be downloaded and stored on the communicator for subsequent viewing. His preferences are for all sports items to be handled in this fashion. John will view them when he is on the plane.

Once John reaches the airport, the communicator provides him with a plan of the route to the gate. The communicator uses the W-LAN system to link into the airline's network and electronically check-in, presenting John with his seat number. John remembers that only 10 years ago he bought his laptop as well as his communicator. Now he sees little point in the laptop. There is no need for a keyboard as speech recognition provides the primary interface. The screen on his communicator is sufficient for the viewing of most images and in any case hotel rooms provide large screens which his communicator can utilize, communicating with them using BlueTooth. He can access any information he desires from almost any location with the high speed download capabilities of his communicator.

Flying has become much more pleasant. The seat back has a large display which John can use for many purposes. He can use this as a screen for his PDA, which he does initially to watch his pre-stored news video clips. He can play games based on his PDA such as chess, interactively if he so desires. Communication from plane to ground has become much less expensive so John is happy to receive incoming calls and emails although he still chooses not to make video calls whilst airborne.

[1] Based on the book *The Future of Wireless Communications* by William Webb, Artech House, May 2001 (www.artechhouse.com).
[2] *William Webb is a Managing Consultant at PA Consulting, email william.webb@paconsulting.com.*

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Arriving at the airport, John's communicator informs him that if he leaves now for the customer meeting he will arrive 15 minutes early. Would John prefer to wait at the airport? John asks the organizer for a list of coffee bars at the airport and the prices of a Café Latte. The organizer finds one that meets John's preferences nearest to him, provides him with directions, pre-orders his coffee and debits his electronic purse in-built into the organizer. His coffee is waiting for him when he arrives. Whilst drinking the coffee, John requests a refresher on the history of the company he is visiting and watches the video clip downloaded over the airport W-LAN system. His communicator informs him when it is time to leave and directs him straight to where a hire car is waiting for him.

When John arrives to meet his customer he talks with him about the changes that have taken place in communications since his last visit. They compare the features and functionality of their latest organizers and some of the latest advances. John's communicator integrates with heart rate and blood pressure monitors interwoven in the fabric of his shirt and monitors the information for irregularities. His colleague has a miniaturized version built into his wrist watch. This makes use of retinal projection to produce what appears to be a full sized image when raised up to eye level.

At night, in his hotel room his communicator dims the lighting, locks the door and prepares the room for John to go to bed. It informs John of his schedule the following morning and suggests an appropriate wake-up time. John accepts. Before going to sleep he reads some more of a recent novel displayed on the screen of his communicator.

II. KEY OBSTACLES EN ROUTE TO A FUTURE WIRELESS SOLUATION

If we examine John's day we might initially think that he has gained much over the communications capabilities that he had available to him in 2002. Certainly, those trying to retrieve voicemails with the mobile phone in one hand whilst trying to drive the car and simultaneously navigate with the other hand will find their life much improved. However, almost all of what John achieved is possible with today's technology. All that has happened is that these capabilities have become more ubiquitous and better integrated. To understand why John's day worked out the way it did, we now take a look at the key constraints and developments that we predict will occur over the coming years.

There are many constraints that will need to be overcome before this type of communications network can emerge - these include:

- The fundamental constraints with wireless communications: bandwidth is scarce, providing ubiquitous coverage is problematic, the radio channel is hostile, battery power is scarce and devices generally need to be portable.
- There are a number of laws and observed principles which shape the way that technology evolves and is able to evolve. Moore's law tells us that processing devices will rapidly become more powerful and less expensive. Shannon's law tells us that there is a limit to the amount of information which can be transmitted through a mobile radio channel.
- Because of the limited capacity per cell, small cells will need to be deployed in order to provide the overall system capacity required. These bring a range of problems especially the cost of backhaul of information.
- If no standard is developed in a particular area this will provide a severe constraint on the future as standards are critical to enable widespread wireless communications. Where standards are developed they take some 4-6 years, limiting the speed at which change can occur.
- To gain the bandwidth required it is necessary to move to increasingly higher frequencies which result in more problematic propagation. This will result in the spectrum available in large cells being little more than available today, but in small cells and fixed wireless systems very much more spectrum will be available – typically of the order of 100 times more than today. The implication is that high data rate communications in large cells will be expensive but that very much higher data rates will be achieved in small cells and fixed systems.
- Higher frequency operation requires more expensive devices. This will keep operation of W-LAN and PAN systems below 10GHz.
- Unlicensed operation will become problematic as more devices use the same spectrum. In particular, fixed wireless systems will not be able to use unlicensed bands in the long term, but they may remain viable for W-LAN and PAN systems if they are designed to intelligently overcome interference.
- Environmental issues such as health concerns and landscaping issues present serious problems to the operator now but these are likely to lessen rather than increase as time goes on and cells become smaller and lower power.

By considering the current position, the willingness of users to pay for particular features and the constraints, we can develop a carefully constructed vision of the future. The next section discusses how we expect the architecture that will support John's needs will evolve.

III. The Network Architecture of the Future

Based on detailed analysis developed in [1] we believe that the key architectural developments will be as follows:

- By 2005 many office buildings will have wireless networks and homes will be starting to deploy BlueTooth networks. By 2010 these networks will be widespread. Communicator devices will be multi-mode and will be able to interwork with all these different types of networks.
- Intelligence will be provided by an "intelligent function" – a computer database within the network able to perform message storage and redirection depending on user preferences. Early versions relating to a single network deployed soon, but full interoperability with all networks not achieved until 2010.
- Broadband connections to homes in the developed world will become common to high end residential customers by 2005 and to all customers by 2010.
- W-LANs will be deployed in dense urban areas, perhaps by 2005 onwards.
- We expect data rate requirements to the home to rise by many orders of magnitude and we predict what these might be in more detail in [1].
- Communication capabilities (initially provided by BlueTooth) will be widespread within high-end consumer electronics devices by 2005 and within most devices by 2010. Because of the replacement cycle for devices it may take until 2015 before most devices in most homes can communicate wirelessly.

Based on the constraints of wireless transmission we expect that there will be a number of different networks in different areas but that these will all be integrated together. This is a conclusion that was shared by many experts in the field of wireless communications who contributed to this work. A diagram of the network might look somewhat like Figure 1.

This may not appear a radically different architecture from the one that we have today, but equally we should remember that the architecture of 2002 is not radically different from that of 1982. There are broadly five different networks here:

- The in-home network composed of a number of short-range radio devices, probably based on BlueTooth, communicating with many different devices in the home. These are linked back to a network hub using in-home backhaul, perhaps along the telephone wiring in the home or perhaps wirelessly. The home network hub is linked to a high-speed connection into the home. The mobile phone utilizes the BlueTooth standard when in the environment of the home and the information passes back though the high speed fixed network to the core IP network and onto the cellular network.
- The in-office network, which might be in addition to the office Ethernet or might form the only network in the office. This might be based on W-LAN standards. The office network is linked via a high speed connection from the office into the core IP network. This connection is more likely to be a wired connection, probably fiber optic, to provide very high data rates, rather than the connection from the home, which is more likely to be wireless.
- W-LAN type systems deployed in dense areas such as public buildings, malls, airports, etc, to provide public service.
- The cellular network, with a similar architecture to today's networks with the exception that the backbone is IP-based using distributed intelligence, as opposed to today's systems which have a circuit-based switch with centralized intelligence.
- The fixed wireless network, where needed, looking very similar in structure to the cellular network and possibly sharing parts of the infrastructure and core network.

Interworking between these networks is achieved in two ways. Mobile terminals are multi-standard and are able to communicate with the cellular, in-office, public W-LAN and in-home networks. The in-office, public W-LAN and in-home networks are able to recognize the presence of a mobile phone and route information back to the cellular network such that services can be provided in a seamless manner. There is no need for interoperability with fixed wireless networks as these only communicate between fixed points.

The second level of interoperability is the common core network, using an IP protocol and a common redirection and message storage function. This ensures that when any device registers on any network, information can be sent back to a common point, perhaps owned by a third party, perhaps owned by a cellular operator, and that common services can be invoked.

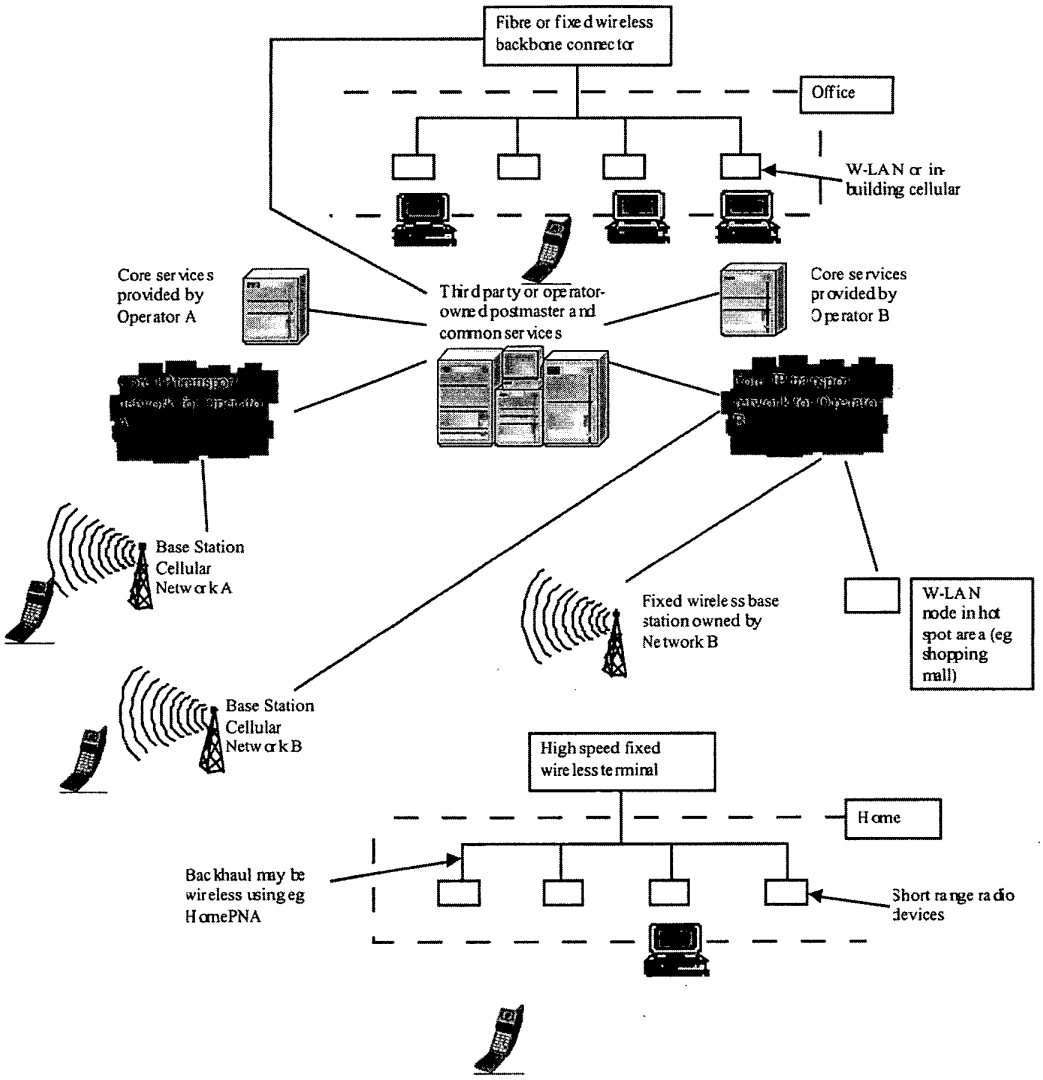

Figure 1 – A possible future architecture for a converged mobile communications network

IV. Coming Closer to Home...

The Need for Advanced ICs

One of the key advances required to enable the network of the future discussed in this paper is for mobile terminals that are considerably more advanced than those in use today. These terminals need to be:

- Multi-band and multi-mode, probably including 2G cellular, 3G cellular, BlueTooth, 802.11b W-LAN capability, 802.11a support and other standards that will emerge over the next decade.
- Powerful software such as speech recognition, image processing and video compression.
- Small and relatively inexpensive such that the majority of the public is able to own one and willing to carry it about with them throughout the day.

Meeting these requirements will require significant advances in IC technology. Today, multi-mode support is starting to emerge but as yet W-LAN support is not enabled on handsets. Most handsets are insufficiently powerful to run anything other than simplified speech recognition. Handsets which go some way towards combining PDA and cellular functionality are expensive and bulky and tend to have relatively poor battery life. It

is easy to simply point to Moore's Law and comment that all these problems will undoubtedly be solved - and we expect they will - however, designers need to have the direction and incentive to tackle them.

Key areas that would seem to require further work include:

- Multi-mode chipsets, incorporating W-LAN functionality but with low battery drain.
- Advanced processor chips able to handle computationally intensive tasks (perhaps including baseband processing for the radio system) with low current requirements.
- Adaptable solutions that can download changes in protocols (e.g., a new profile for a BlueTooth connection).
- RF systems able to work across a wide band of frequencies (potentially 800MHz to 6GHz) with varying power levels and linearity requirements which are compact and power-efficient.

Many other areas will also likely require significant advances, and new requirements will emerge over time as the future evolves in unexpected ways.

V. Summary of the Future

In outline we expect the future of wireless communications to be a very bright one. Almost everyone in the developed world will carry a wireless communicator which they will use many times during the day. They will perceive immense value from the services that this communicator provides and this will be reflected in increased ARPUs which in turn will drive the industry with increased growth and investment. Enormous expenditure will occur as networks are constructed outdoors, in offices, in public spaces and in the home. Wireless capabilities will be embedded into almost all devices – even perhaps clothing.

Looking at networks, we do not expect to see one single radio solution providing coverage everywhere. Instead, there will be a multiplicity of different networks – something that already exists today. What will be different in the future is that all these networks will work together in a manner not currently possible. This will be achieved in two ways. Firstly, devices will be multi-modal and so able to work on almost any network that they discover. This will become economically viable as advances in IC technology reduce the cost premium of complexity. Secondly, the networks themselves will be able to interwork through the sharing of a common IP-based core and the development of intelligent call routing functions able to deliver calls to subscribers wherever they are in an appropriate manner.

These changes will provide the underlying framework for an extraordinary change in social behavior – an information revolution. This will be driven through the availability of communicator devices able to perform a wide range of functions with which people can interact in a simple and intuitive manner. This will be enabled through the rapid development of applications and content which will occur as wireless networks move to an Internet model whereby applications can be created at the edge of the network and downloaded to any entity connected to the network. Improved interfaces on the communicators including large color screens, speech recognition and more will increase their capability to handle complex content. New means of communications including video phones and high data rate transmission will drive societal changes such as home working. These, in turn, will lead to new applications and devices. The evolution of wireless has the potential change the world as we know it.

Of course there are risks and uncertainties involved in painting this picture of the future. Operators are likely to encounter turbulent times as their costs increase with auction fees whilst the type of network and the competition from W-LANs may cause them problems. Virtual operators, global brands and new entrants will change the face of the industry as we know it today. The environment will be confused for many years as new entities enter and many new concepts are tried and fail. However, the end result is so obviously advantageous and the willingness to pay for this so clear that failures will be tolerated in the quest to be a leader in the new connected world.

About the author

William Webb graduated in electronic engineering from Southampton University, UK with a first class honours degree and all top year prizes in 1989. Since then he has been awarded a PhD and an MBA. From 1989 to 1997 William worked for a range of communications consultancies in the UK in the fields of hardware design, computer simulation, propagation modelling, spectrum management and GSM standardisation. In 1998 he moved to Motorola in the USA where he was responsible for strategic management across Motorola's entire communications portfolio and in 2001 to PA Consulting where he is a Managing Consultant in the Wireless Technology Practice. William has published over fifty papers, holds four patents, a number of awards, is a fellow of the IEE, a senior member of the IEEE, and is the author of seven books including *The Complete Wireless Communications Professional* and *The Future of Wireless Communications*. He has a monthly editorial column in *Wireless Europe* and is listed in *Who's Who in America*. He can be contacted at by phone at +44 1763 267061 or at william.webb@paconsulting.com.