Virtual University Research Initiative on Mobility

R M Dennis, A R Beresford and K M Brown

BT's technology acquisition has taken on an increasingly collaborative approach in recent years. This paper provides an insight into a long-running collaboration between BT and three universities in the mobility area.

1. Introduction

The Virtual University Research Initiative (VURI) on Mobility is a corporately funded research project, which has looked at a wide range of topics and issues in the mobile radio and mobility area over several years. Although it has included other universities over this period, its success can be attributed to BT's long-term relationship with three UK universities — Birmingham [1], Bristol [2] and Oxford [3]. This relationship has provided a reservoir of skills and expertise, which have remained reasonably consistent throughout considerable changes in BT's research and development objectives in the mobility area.

The project has had a number of BT managers, and been associated with several different research and development units. This paper will chart this relationship and its benefit to the business as well as looking at the future significance and direction of the VURI.

2. Background — brief history of the VURI

In 1994, an audit of corporately funded research revealed a lack of expertise in the (then) new third-generation mobile technologies. The VURI was subsequently set up in 1995 to carry out research along lines suggested by both BT and the member institutions, and also act as a non-industrial expert group. The set-up of the VURI was also an experiment into a new way of organising university research — the universities and BT's laboratories at Adastral Park are all members of one 'virtual university' despite having a number of bases around the country. All VURI members have both individual projects and a commitment to working together in collaborative work.

The VURI project has been a useful test bed for assessing this style of managing large-scale, long-term research. The particular form of the VURI — made up of academics from different institutions together with BT researchers — has proved to be an effective way of generating reliable reports on a wide variety of technological issues. The range of expertise generates (often opposing) viewpoints on a variety of topics, either throwing up new areas of research or allowing identification of the underlying issues in a given area. The VURI has been successful in seeding research at BT's laboratories in the mobility area and is now starting to provide graduates who are both technically skilled and commercially aware.

Three universities were chosen to work together in initial phase of the VURI — Oxford, Birmingham and Bristol. Each institution has specific, yet complementary strengths:

- Birmingham is very strong on the theoretical and analytical aspects of mobile communication, and signal propagation in particular,
- Oxford was motivated from a practical side, providing real-time measurements and analysis,
- Bristol combined elements of both, looking at the mobile system from a wider perspective, and using real data combined with theoretical predictions to build models of the performance of mobile networks in a variety of scenarios.

2.1 Original vision — 'A factor of one-hundred-fold increase in capacity'

Initially, the vision for the VURI was to develop methods that would result in an increase in mobile network capacity between a factor of ten and one hundred in an economical and viable way. Some of the early projects focused on GSM networks, looking at issues such as cell planning, but, for the most part, attention was on different transmission techniques — in particular spread spectrum. It was clear that increasing the available bandwidth would immediately increase capacity, but the main interest was in finding ways to optimise the use of spectrum. In the light of the UMTS spectrum auctions and the vast prices which broadband spectrum is commanding, this is just as relevant today.

As the VURI research progressed, VURI members (including BT) were working together on projects which would be the key to the provisioning of third and fourth-generation mobile services, but which did not fit with the original vision. In 1999 a re-appraisal of the VURI led to a new objective and soon after the responsibility for the project was handed over to the current custodians, the Mobility Futures team in BTexaCT Research at Adastral Park.

2.2 Current vision — 'How do we (BT) best provide mobile customers with services that are both flexible and reliable'

The current vision encompasses some of the original physical layer activities, but more importantly ensures the VURI will look at the bigger picture — advancing the technology used in mobile networks to provide services with increased flexibility and reliability.

3. Achievements to date

The VURI's achievements fall into two categories — hard deliverables (including papers and reports), and influence (a sounding board that includes consultancy). Although the former is measurable, the latter is far more subjective and difficult to assess fully, given the degree of people movement in BT.

3.1 Influence

Apart from the numerous conference proceedings and panels, the VURI is acknowledged as playing a significant role in the UMTS standardisation process. The VURI was involved with the trials of manufacturers' equipment and provided input to BT's Third-Generation Licence bid team.

The Exploiting Mobility Conference, at BT's laboratories at Adastral Park in 1998, was a two-day event 'to showcase the work of the Virtual University Research Initiative on Mobility'. Presentations and poster sessions explained technical detail of the VURI work and its application to UMTS systems. The conference was attended by people from across the business and a number of invited external guests. The presentations were well received and the conference succeeded in increasing the visibility of the VURI, providing a catalyst for several collaborative projects within the BT 'Exploiting Mobility' campaign.

3.2 Papers and reports

The VURI to date has produced over 50 conference and journal papers; a list of papers together with abstracts is available from the BT VURI Web site [4]. Research has covered a wide range of topics, although the majority can be grouped into six broad categories:

- modelling and measurement of radio propagation in a variety of indoor and outdoor environments,
- adaptive antenna systems,
- mobile network systems modelling and measurement,
- theoretical analysis of electromagnetic diffraction and scattering,
- advanced modulation and coding schemes,
- UMTS enhancement techniques.

4. Current focus

The nature of the research and the extensive use of PhD students at its core means the VURI has a certain built-in inertia. This is not a barrier to its value, although care is needed to ensure the focus remains current and aligned with BT's vision and long-term business goals. The VURI's overall vision has to be concise and clearly communicable both inside and outside BT and the wider research community. With the recent changes in BT, the current focus has recently been reviewed and is in the process of being updated; the suggested focus is 'Ultimate mobility — freedom to roam with a single terminal'.

Currently, the mobile industry is looking to software defined radio (SDR) [5] to solve some of the problems, given the wide variety of mobile networks across the world (see Appendix A for details). The work and expertise of the VURI will be used to assess and quantify the advantages and disadvantages of the mass-market SDR for both the consumer and the network operator. Fundamental questions and possible topics under consideration are likely to include the following.

- What effect does SDR have on quality of service and achievable data rates? Is SDR capable of some of the advanced transceiver architectures possible in custom hardware? What effect will this have on network capacity?
- When will SDR become cheaper/lighter/smaller than a hardware solution? How does additional functionality needed in the device (e.g. PDA) alter the dynamics?
- What effect does SDR have on operators upgrading their networks? Will it increase or decrease the number of different types of network in operation?
- What percentage of customers would benefit sufficiently from SDR to invest in the new technology?
- What are the technology drivers that will underpin an impact in the various global markets?
- What factors can the BT Group and its partners use to differentiate its products and services?

With greater than one billion mobile subscribers predicted by 2003, BT and its alliance partners will be looking for differentiation based on service offering to gain its share of global mobile subscribers. The trade-off between an all-hardware device and a reconfigurable software solution needs to be understood — it is anticipated that the network requirements and service options for operators will directly reflect the approach taken.

The new focus aims to forge stronger links between BT research projects and the other VURI members, possibly combining this work with strategic suppliers or collaboration with one or more of the start-up companies active in the area. Ideally, this would form a 'knowledge staircase', with the VURI as a foundation with measurements, simulation and theory.

5. Relationship with the VCE

The Mobile VCE [6] is a consortium of twenty-three telecommunications operators and equipment manufacturers (including BTCellnet) which fund and co-ordinate research at seven UK universities. The goal is to investigate what a fourth-generation mobile network will look like in 2010 (see Holley and Hall [7] for more detail on the VCE).

The VCE is important to the VURI, since it provides a wealth of knowledge and research that can be built on. However, it is important to manage VURI research carefully — to avoid duplication of work. The VURI research is co-ordinated with this in mind, building on the work of the Mobile VCE. The VURI has the advantage of being able to use the VCE work in a BT-specific context while avoiding the problems associated with the decision-making process inside a large and diverse industry body.

The VURI research programme will allow BT to differentiate its network and service offering in 2010 from other Mobile VCE consortium members. No conflict or duplication exists between the VURI and the VCE and it is BT's responsibility to ensure this position continues.

6. Business benefit

The VURI is not unique in its collaboration with universities. Several corporately funded projects have large numbers of university contracts with more than one academic institution. BT has funded several 'Strategic University Research Initiatives' over the years, building a relationship with a single key academic institution in a particular research area. The VURI differs mainly because the relationship is a collaboration between four partners. BT looks to provide a vision, identity and strategy for the work, but also attempts to foster collaboration between the various universities independent of its own internal research. This allows the VURI to remain effective and continue to move the vision forward even during periods of uncertainty within BT resulting from, for example, re-organisations and short-term distractions.

As with any long-term investment, the value of the VURI cannot be judged simply by looking at its perceived value at any one instance in time. The true business benefit of the VURI since 1995 should be considered as a combination of the following factors:

- quantifiable achievements and their impact on the issues of the day,
- cost of acquiring the expertise inside or outside of the business,
- time required to build and develop the equivalent in-depth competence internally,
- consistency of research focus independent of short-term business pressures,
- value of the relationship,
- value of recruitment potential from the VURI member universities,
- ease of access to academic and industry-wide contacts,
- credibility and perception of BT's competence in the area with internal and external customers.

One of the key benefits of a long-term relationship with the academic community is the opportunity to recruit high-quality, business-aware students. This has provided BT with invaluable expertise in the evaluation of prototype UMTS equipment and BT research in general.

The VURI also has a public relations role both internally and externally. Internally it provides a route for BT's researchers to work with world-class experts as their careers develop. Externally, visibility of BT's involvement with in-depth research adds credibility to its desired position as an industry leader.

7. 2000/2001 programme

Senior university researchers (see Appendix B) have provided the driving force over the years, although the VURI only directly funds a combination of Research Assistants (RAs) and PhD students at each university. The RAs take a more responsive and short-term role in addition to their involvement with the core research, which is done mainly by PhD students in three-year projects. This combination of consistency with the opportunity to address some of the more short-term problems allows BT to gain help with some of the 'fire-fighting' issues while minimising disruption to the underlying research work. Fine-tuning the focus on a regular basis provides longer-term control of the overall direction.

With the change to the BT organisation in early 2000, the inherited programme has been extensively reviewed and plans put in place to update the focus over the next three years.

The primary expertise of the key individuals at the three universities is at the physical (radio channel) layer. Although this expertise is critical to the success of the VURI, the value of adding a new partner is actively being considered to augment the skill-set and maximise the value of the physical layer work. Improved awareness of the impact and requirements of services and applications could provide BT with a faster route from the fundamental research to real or perceived differentiation in the market-place. Several options are under consideration including non-UK institutions, possibly one in the USA with which BT already has a strategic relationship (i.e. MIT or Berkeley).

The case study (see Appendix C) is an example of the work continuing in the 2000/2001 annual programme. This work involves BT, Birmingham and Oxford, although Oxford is in the process of beginning a new programme of work that is still being defined. Bristol are currently looking at improvements achievable by organising the wireless infrastructure and the wired backbone network on a more global scale. In particular, they are researching self-organising network techniques, including the concept of situation awareness. The aim is to allow the wired and wireless network to make use of information both from base-stations and from supporting network nodes to enhance performance globally.

The majority of the work in the current programme fits in well with the suggested focus — however, a healthy debate remains as to whether the SDR focus is in fact too restrictive to encompass all of the VURI's potential contributions to the mobility area.

8. Future direction

Given the approach already discussed in this paper, much of the research work of the VURI in the medium-term (2000—2003) is already reasonably well defined. In the longer term the VURI will provide the foundation for fourth-generation systems and, perhaps more importantly, identify potentially disruptive technologies. SDR or re-configurability has already been discussed but other areas include new and enhanced coding schemes, smart antennas and *ad hoc* mobile networks.

Wider visibility of the VURI and its work is still needed. For the 2000/2001 programme, the annual review meeting will enable effective academic peer review of work carried out. The recent addition of an external VURI Web site [4] (outside the BT firewall) will also increase the general academic access to VURI work.

BT is continuing to ensure the true potential of the VURI relationship is achieved, including realising the commercial potential of the some of the VURI's work. Projects like the channel sounder (Appendix C) are ripe for development by manufacturers under licence.

9. Conclusions

The VURI research methodology fits well with BT's current approach to technology acquisition, with less being done directly in-house and more resulting from collaborative work. This paper has shown how the approach works in practice and demonstrates the importance of in-depth internal competence to maximise the advantage generated.

The VURI is a unique relationship that BT has had the foresight to build and maintain over several years. Realistically, funding of the VURI has to be corporate, and as such will always be vulnerable to short-term pressure. However, the VURI is not only justifiable because of its quality of research, but also its reservoir of specialists and expertise which can be used to complement BT's competence.

Acknowledgements

The authors gratefully acknowledge the help and support of all their BT colleagues who have been involved with the VURI. We would also like to take this opportunity to acknowledge all the various academic members of the VURI both past and present for their contributions to the project.

Appendix A

VURI technology update — software radio and software defined radio

The software radio (SR) [5] revolution extends the migration from analogue to digital by liberating radio-based services from a dependency on hard-wired characteristics. In 1995, Mitola coined the term 'software radio' and effectively defined the whole area [8].

The essence of the SR concept is the ability to update the different functional components of a radio system dynamically and is achieved by configuring re-programmable hardware with software. The reconfiguration can be achieved by a software download over a radio link or via a wired network. Apart from the ability to offer multi-band configurations, the approach can be used to upgrade the handset, e.g. when new standards are released. Taken further, SR can be used to adapt the hardware dynamically (e.g. change of codec) in an attempt to maintain quality-of-service targets or improve coverage. SR is not a new technology, but an evolution and convergence of digital radio and software technologies.

Providing reconfigurability after leaving the factory requires general-purpose hardware that can cope with the constraints of all the mobile radio communications standards. SR devices digitise signals directly from the antenna and all the processing is performed by software residing in high-speed digital signal processors (DSPs). Limitations in DSP technology prevent construction of SR terminals in the short term; however, significant re-configurability can be gained using software defined radio (SDR) — performing digitisation at some stage after the reception and analogue processing. As technology progresses, an SDR handset will provide increasing functionality, ultimately culminating in an SR device.

Industry experts suggest SDR systems will be available as early as 2003 in both base-station and handset configurations. Although BT is unlikely to build handsets or base-stations, it is essential to be aware of the evolution of programmable hardware because of the impact it will have on increasing the flexibility and adaptability of the network. With global procurement based on a 'vanilla' set of programmable building blocks, BT needs to understand the capabilities and limitations of this technology in order to maintain its ability to differentiate based on the relationship between the network and the service or application.

Appendix B

VURI member institutions — the key university researchers

The Communications Group [3] within the Department of Engineering Science (headed by Professor David Edwards), at Oxford University, is broadly split into three areas — Future Radio Systems, Advanced RF and Microwave Devices, and Radar and Antenna Systems. Combined, these three groups provide the VURI insight into propagation measurement and modelling, adaptive antennas, and application of advanced materials in communications systems.

Professor David Edwards returned to academia in 1985 after 12 years with BT. He has contributed to more than 150 publications in the fields of radio and optical communications systems, electromagnetics and signal processing. Currently he is the Professor of Engineering Science at the University of Oxford. He has been in receipt of a number of awards for his research work and currently his interests cover mobile radio communications, free-space optical communications, high-temperature superconducting components for communications, and imaging techniques for communications and medical applications. He is a Fellow of the IEE and the Royal Astronomical Society.

The Communications Engineering Group [1] (where Costas Constantinou heads the radio wave propagation research activity), within the School of Electronic and Electrical Engineering, Birmingham, provides the VURI with expertise on propagation measurement and fundamental electromagnetic propagation theory as well as dynamic system control and network issues.

Costas Constantinou was born in Famagusta, Cyprus in 1964. He received his BEng (Hons) in electronic and communications engineering and PhD in electronic and electrical engineering degrees from the University of Birmingham, in 1987 and 1991, respectively. In 1989 he joined the School of Electronic and Electrical Engineering at the University of Birmingham as a full-time lecturer and, subsequently, as a senior lecturer.

He currently heads the radio wave propagation research activity in the communications engineering research group. His research interests include optics, electromagnetic theory, electromagnetic scattering and diffraction, electromagnetic measurement, radio wave propagation modelling, mobile radio, and future communications networks architectures.

He is a Fellow of the IEE and the Royal Astronomical Society.

The Centre for Communications Research [2] (where Mark Beach leads the CDMA and adaptive antennas research programmes), within the Electronic and Electrical Engineering Department at the University of Bristol, has teams working in RF engineering and wireless communications systems. Currently, Bristol provides the VURI with expertise on situation awareness in self-organising networks and mobile network system simulation and modelling.

Mark Beach received his PhD in 1989 from the University of Bristol for work on adaptive antennas for multiple spread spectrum signal sources, primarily targeted towards GPS receiver technology. Post-doctoral research at Bristol included work regarding the application of adaptive antenna techniques to mobile cellular networks for which the research team received the IEEE Neal Shepherd memorial prize in 1990. Since August 1990, he has been engaged as a member of lecturing staff at Bristol and leads the CDMA and adaptive antennas research programmes within the Centre for Communications Research. In particular, he has led Bristol's activities on smart antennas under European funding from RACE, ACTS and now IST. This includes projects such as TSUNAMI, AWACS and SATURN, as well as helping the CEC launch the First European Colloquium on reconfigurable radio systems and networks in March 1999, from where projects such as TRUST were conceived. At present he holds the post of Reader in Communication Systems at the University of Bristol. He is also a serving member of the IEEE 8 Professional Group on Radio Communication Systems.

Appendix C

VURI case study — radio channel photography

If the BT Group and its alliances are to maximise return from their investment in third-generation (3G) mobile telephone licences, it must produce a range of services which derive benefit from the high data rates available. Voice calls can already be carried on the existing second generation (2G) networks. 3G can only attract the volume of subscribers required by offering new and improved services and applications to provide the differentiation. To achieve the capacity and coverage required for high data rate services on 3G networks, careful planning and modelling is essential.

It is anticipated that planning will be site specific and propagation models must accurately predict power levels as well as temporal and spatial channel characteristics. For example, the angle of arrival information of each of the multipath radio wave components can be used to estimate the capacity enhancement possible from advanced technologies such as beam-steerable antenna systems.

Current propagation modelling techniques are based on ray-tracing, but such systems must make assumptions. Accuracy is fundamentally limited by the level of detail available about the environment as well as the amount of computational power available to run the simulation. Currently, ray-tracing simulations result in poor accuracy when modelling deep shadow regions, commonly found in urban environments.

The VURI has designed and built a channel sounder to accurately measure the spatial and temporal channel characteristics of radio environments. The channel sounder hardware combined with computer post-processing allows construction of a 'picture' showing what the radio environment looks like at different time instants (see Fig A1 for an example).

The results from such studies should improve the accuracy of planning tools and simulation software. It is hoped that propagation modelling techniques will improve sufficiently to allow accurate models to be made despite fundamental limitations. However, it is unlikely that optimum network performance will be achieved without performing some measurements at each cell site.

Several VURI papers have been produced [4] through collaboration between the various VURI members and BT researchers. Further work is under way, including construction of a more accurate and portable channel sounder.

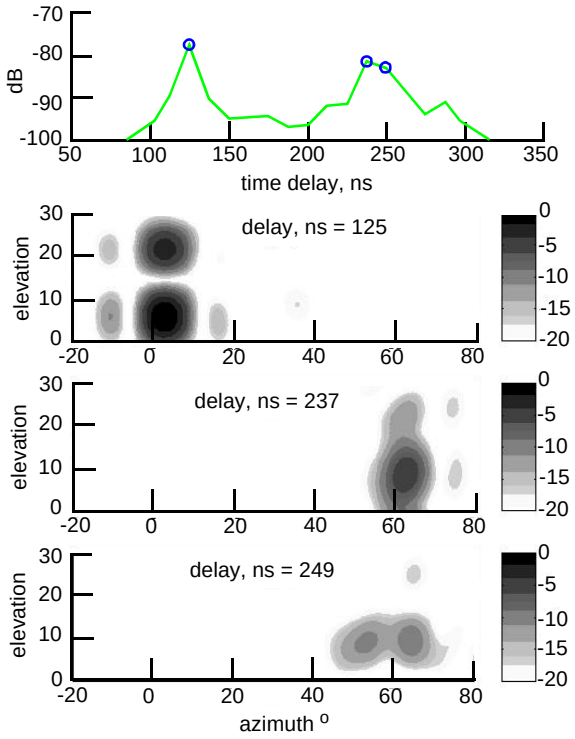

Fig A1 Channel impulse response (CIR), shown top, demonstrates the variation in signal strength against time. Three radio images (bottom) show direction of arrival information for the peaks marked on the CIR. The data was collected at Birmingham University and forms part of a paper [9] at VTC2000 [10].

A BT joint venture company has already expressed interest in buying BT's channel sounding equipment, and more interest is expected as the industry struggles with the current models and planning techniques. The aim is to ensure BT Wireless has this technology available — ahead of it competitors — and before it becomes essential.

References

1 Communications Engineering Group, Birmingham University — http://www.eee.bham.ac.uk/com_gr/

2 Centre for Communications Research, Bristol University — http://www.een.bris.ac.uk/Research/research_index.htm

3 Engineering Science Department, Oxford University — http://www.eng.ox.ac.uk/~comwww/

4 VURI Web site — http://www.btvuri.com/

5 SDR Forum Web site — http://www.mmitsforum.org/

6 Mobile VCE — http://www.mobilevce.co.uk/

7 Holley K A and Hall K G: 'Virtual centre of excellence in mobile and personal communications', BT Technol J, 19, No 1, pp 19—23 (January 2001).

8 Mitola J: 'The software radio architecture', IEEE Communications Magazine, pp 26—38 (May1995).

9 Mughal M J, Street A M and Constantinou C C: 'Detailed radio imaging of buildings at 2.4 GHz', IEEE Vehicular Technology Conference (September 2000).

10 Vehicular Technology Conference 2000 — http://www.vtc2000.org/

Richard Dennis joined BT Laboratories as an apprentice in 1972. He is a Chartered Engineer and a member of the British Computer Society

He started work on the trunk circular waveguide project and during his career has been involved in ISDN terminal design, multimedia standards, strategic development and R&D analysis for the corporate research programme.

He is currently the head of the Mobility Futures team in BTexaCT Research at Adastral Park.His team became responsible for the VURI research project in Jan 2000.

Alastair Beresford was a BT sponsored student and received a first class honours degree in Computer Science from Cambridge University in 1999. He joined BT in October of that year, working in the mobility futures team within BTexaCT Research at Adastral Park.

His current research interests include radio propagation and *ad hoc* networks, in particular ODMA systems. He returned to Cambridge University in October 2000 to study for a PhD in the Laboratory for Communications Engineering.

Katie Brown graduated from Aston University in 1992 with a Masters degree in electronic systems engineering. She stayed at Aston to complete a BT-sponsored PhD in Dark Optical Soliton theory, and joined BT in 1995 to work in the newly formed Exploiting Mobility campaign.

Her early work for BT included radio propagation and channel modelling. She is now a mobility applications developer in BTexaCT at Adastral Park.