Institution: University of Bedfordshire

Unit of Assessment: 11- Computer Science and Informatics

Title of case study: Enabling high-quality, low power mobile broadband services

1. Summary of the impact

Femtocells provide short-range (e.g. 10m) wireless coverage which enables a conventional cellular communication system to be accessed indoors. Their widespread and growing use has been aided by the work in UoA11 by the University of Bedfordshire (UoB).

In 2008, while the femtocell concept was still in its infancy, researchers at UoB with expertise in wireless networks recognised that coverage prediction and interference reduction techniques would be essential if the benefits of that concept were to be realised.

Collaboration with two industrial partners (an international organisation and a regional SME) resulted in tools that enable operators to simulate typical femtocell deployment scenarios, such as urban, dense apartments, terraced house and small offices, before femtocells can be reliably deployed by users without affecting the rest of the network (a benefit of the technology). These tools have been deployed by those partners to support their businesses. A widely-cited textbook, written for network engineers, researchers and final year students, has brought knowledge of femtocell operation to a wider audience.

2. Underpinning research

The research team

(Where a researcher has left the University of Bedfordshire, the leaving date is shown.)
Group Leader: Prof. Jie Zhang (Jan 2011)
Lecturer (now Reader): Dr Enjie Liu
Senior Research Fellow: Dr Guillaume de la Roche (May 2011)
Research Fellow: Dr Zhu Xiao UoB (March 2012)
Marie Curie Research Fellow: Dr David Lopez-Perez (July 2010)
Research student: Dr Alvaro Valcarce (July 2010)
The research was carried out between 2008 and 2010.

Background and problem to be solved

The femtocell concept had been under discussion among wireless network experts since 2006, but its realisation was impeded by a lack of suitable communication protocols and an understanding of the nature of the radio channel in the confined space in which a femtocell operates, together with the associated sources of interference and ways of combatting their effects. The Centre for Wireless Networks at UoB (CWiND) had built up extensive expertise and knowledge in network management and protocols, and in 2008 was one of the first research groups to propose the possibility of using WiMAX technology and protocols for building and deploying femtocells. The research began in UoB in 2008 under an EPSRC-funded project in the 'Digital Economy' theme. The fact that CWiND had already been actively involved in wireless network planning and optimisation meant that the relevant expertise was available to make a rapid and effective start to the initial project.

Approach

The research started by identifying some key technical challenges in WiMAX-based femtocells, namely Interference, mobility management and auto-configuration. The challenges of using WiMAX technology in building and deploying femtocells identified by our research have been recognised by other researchers as well, as noted in Section 3.

Research was carried out to investigate these challenges. This was initially under an EPSRC-funded project, then in cooperation with, and funding from, T-mobile (a telecoms operator) and RANPLAN (an SME). The elements of the research and the resulting transferable knowledge and experience may be summarised as follows.

- An experimental evaluation of the effect of interference caused by femtocells on the associated macrocell, [3.1], [3.6]
- Characterisation of the indoor-to-outdoor propagation channel through an extensive channel measurement campaign in a residential area. The collected data was used to calibrate a Finite-Difference Time Domain (FDTD) propagation model, which is now a

reference tool for the accurate prediction of signal coverage [3.7].

- Prediction of channel fading distributions in a femtocell scenario. The developed model can be used in the femtocell deployment tool in modelling channel fading [3.3].
- Development of an indoor radio propagation model, which can be used by network planners to aid effective femtocell installations [3.2],[3.3],[3.4],[3.5],[3.6],[3.7].
- Characterisation of an indoor-outdoor-indoor propagation channel, as a result of a measurement campaign, which produced a new path loss model applicable to femtocell deployment.
- An effective approach to mobility management, especially on cell identification, which is particularly useful for inbound handover in multilayer networks. The solution was based on cell activity level prediction to allocate PCIs, and the results outperformed the existing approach in term of achieved less handover failure [3.8].
- Enhanced interference management techniques applicable to small cells, as a result of measurement campaigns for UMTS/HSPAL/LTE networks at 0.8, 2 and 2.6 GHz in typical residential and business environments [3.7]. (This work was funded by T-mobile.)
- System level simulation (SLS) for WiMAX and UMTS/HSPA/LTE (3G/4G) femtocells [3.1], [3.3], [3.5].
- Interference avoidance algorithms between indoor femtocells and outdoor macrocells [3.4].
- Performance analysis and evaluation (throughput, handover, outage, quality of service) of both femto and macrocell layers based on SLS [3.1], [3.4], [3.5].
- Indoor and indoor-to-outdoor radio propagation models based on FDTD (Finite Difference Time Domain), and 3D ray tracing/launching [.33], [3.6], [3.7].

The project results were disseminated through a series of femtocell workshops. For example, there were 56 participants from both industry (11 companies including T-Mobile, Vodafone, Alcatel-Lucent), and academia (10 universities) who attended the first workshop in 2009. The 5th workshop was held in Feb 2012. The research was also disseminated through EPSRC's Digital Economy impact review.

3. References to the research

A list of the main publications is given below. To date, [1] has been cited 124 times, [2] has been cited 63 times and [5] has been cited 357 times since their publication.

3.1 J. Zhang, G. de la Roche, A. Valcarce, D. López, E. Liu, H. Song, "Femtocells – Technologies and Deployment," Wiley, Jan. 2010, (ISBN: 9780470742983)
(Note: A new book on small cells, a new name for femtocell and its like, was invited by Wiley and the draft is now ready to be submitted.)

3.2 D. Lopez-Perez, A. Valcarce, G. De La Roche, E. Liu and J. Zhang, 'Access methods to WiMAX femtocells: A downlink system-level case study', in Proc. 11th IEEE Int. Conf. on Communication Systems, 2008, Nov. 2008, pp.1657-1662. (Note: Although this is a conference paper, it was one of the first papers on femtocells.)

3.3 G. De La Roche, A. Valcarce, D. Lopez-Perez, E. Liu and J. Zhang, 'Coverage Prediction and System Level Simulation of WiMAX Femtocells', COST 2100 6th Meeting, Lille (France), October 2008. (Note: The COST project itself is Influential, and models presented at COST are generally accepted as bench marks.)

3.4 D. López-Pérez, A. Valcarce, G. De La Roche and J. Zhang, 'OFDMA femtocells: A roadmap on interference avoidance', *IEEE Communications Magazine*, September, 2009.

3.5 G. De La Roche, A. Valcarce, D. López-Pérez and J. Zhang, "Access Control Mechanisms for Femtocells," *IEEE Communications Magazine*, Jan. 2010. (IF 2012: 3.66).

3.6 A. Valcarce, H. Song and J. Zhang, 'Characterization of the Numerical Group Velocity in Yee's FDTD Grid, IEEE Transactions on Antennas and Propagation, Vol 58, Issue 12, 2010, pp.3974-3982

3.7 A. Valcarce; J. Zhang, 'Empirical Indoor-to-Outdoor Propagation Model for Residential Areas at 0.9-3.5GHz', IEEE Antennas and Wireless Propagation Letters, Vol 9, pp.682-685, 2010

3.8 Zhu Xiao, Peng Wang, Xu Zhang, Shyam Mahato, Lei Chen and Jie Zhang, 'Incentive mechanism for uplink interference avoidance in two-tier macro-femto networks', Proc. IEEE 75th VTC, May 2012.

4. Details of the impact

Context to the impact

About 10 years ago, there was interest among telecoms experts in extending cellular coverage so that users could access a network from inside a building without loss of service quality. Several technical approaches to achieve this were considered, and the 'femtocell' name was coined in 2005 for a standalone, self-configuring home base station which did not require a dedicated handset. The in-building wireless access point was intended to communicate with approximately 10 handsets within a distance of up to (typically) 10m. The Femto Forum was set up in 2007 so that manufacturers and operators could obtain and exchange information relevant to small-scale cellular communications.

Impact achieved by the CWiND/CWR team at the University of Bedfordshire

For the femtocell concept to be effective, a range of technical challenges would have to be overcome, mainly those associated with interference, mobility management and auto-configuration (as noted in Section 2 above). Researchers in CWiND (now Centre for Wireless Research, CWR) at the University of Bedfordshire recognised that these problems existed, and with their expertise in wireless networks were in a position to address them through a research programme. Funds were obtained in 2008 from EPSRC to start the first research supported by EPSRC on femtocells; this showed forward thinking at the time, as there were no femtocell deployments when the project started.

The benefits of using WiMAX (as compared with other candidate technologies) were also appreciated by the CWiND team, and the results of the initial research were recognised by the telecoms company T-mobile, and by RANPLAN (www.ranplan.co.uk), a small company located in Luton near to the University who specialise in radio network planning and optimisation. T-mobile already knew of the work of the team, as a result of a presentation given by Prof. Jie Zhang at a meeting of the Femto Forum in 2008, T-mobile proposed a cooperative programme to extend the research findings to cover their specific interests. One of the researchers in CWiND was a was a technical adviser to RANPLAN, and had recommended to that company that the tools developed by the CWiND team (as described in section 3) should be taken up to enhance RANPLAN's ability to offer planning services to their customers. He is now (since January 2011) R&D Manager at RANPLAN Wireless Network Design Ltd.

In the next phase of the work, in 2009, cooperation with and funding from T-mobile resulted in enhanced interference management techniques applicable to small cells, encapsulated in an model provided by the CWiND team to T-mobile applicable to the effect of femtocell/macrocell interactions [5.1]. Consultations with RANPLAN led to investment by that company to incorporate the CWiND team's research results into an existing cutting-edge indoor planning tool which RANPLAN uses extensively in its commercial offering to customers [5.2].

Following the generation of specialised knowledge and experience of femtocells, the team wrote a book [3.1] which covers the principles and practical aspects of femtocell technology and deployment, and which has been widely cited. It has been published internationally, and has been translated into Chinese. The book has been written for researchers, practitioners and installers of femtocells, as well as final year undergraduates. At the invitation of the publishers, which confirms the good impact of the book (at November 2013, more than 700 copies of the English edition had been sold), a second book has been prepared by the same authors to provide an update and expansion of the material in the first book.

The impacts of the work of UoA11 on femtocells (now also known as small cells) can be described under various headings.

The research has economic impact in terms of enabling a new alternative cellular communications technology which can improve data access (speed and capacity) and communications convenience, and thus improve efficiency of working for customers and business reach for operators. The femtocells were deployed after this project started. Effective network planning initially benefits the operators, but it consequently affects the service tariff, and thus benefits the

user business or household.

A knock-on benefit is an ecological one. According to ABI research, by 2014 energy savings from femtocells for operators will be equivalent to planting 12,000 acres of forest. As most major operators have deployed femtocells in their network (this link shows a full list: www.smallcellforum.org/aboutsmallcells-small-cells-consumer-faqs) the CWiND work has contributed to this benefit.

The work in UoA11 on femtocells is timely. According to the Femto-Forum: the number of small cells is growing from 3.2 million in 2012 to 62.4 million by 2016 – a 20-fold increase, constituting 88% of all base stations globally. It aligns with the Government's mission of 'Digital Britain' to increase the quality of life for the general public in terms of research on an alternative wireless broadband access technology.

The research has an impact on society, culture and creativity. The initial results were disseminated through EPSRC's Digital Economy impact review, whose readers include policy makers, researchers and the general public. A full report of the work done by UoA11 with EPSRC funding can be found at: www.rcuk.ac.uk/documents/documents/DEIREvidencePart3-EvidencefromthePortfolioSurvey.pdf .

We attended several conferences which were strongly influenced by industry, such as the Femto Forum conferences in London and Dallas in 2008, while a member of the UoA11 team was the chairman of a femtocell panel entitled "Femtocells: Deployment and Applications" at the IEEE International Conference on Communications (ICC) in 2009.

5. Sources to corroborate the impact

5.1. Senior Head of Research Trials at T-mobile
5.2. R&D Manager at RANPLAN Wireless Network Design Ltd.