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BOURSE – Broadband Organisation of Unregulated Radio Systems through Economics

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BOURSE - Broadband Organisation of Unregulated Radio Systems through Economics

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Abstract

This is a technical report about an idea for research in the intersection of active nets, cognitive radio and power laws of network topologies.

1 Purpose

1.1 Introduction

We are motivated by the current discussions in the US relating to third generation mobile systems. In a significant move, the FCC are proposing to deregulate of sections of the spectrum on the assumption that governmental assessment of the highest valued use of spectrum is often wrong and that a secondary market is the most efficient mechanism for determining this. We believe that the solution lies in a market-based mechanism by which spectrum can be sold to given sets of users, based on ability to pay relative to a proposed set of usage policies and proposed network topologies. Although the mechanisms we propose are somewhat generic, we believe that in order to be of maximum use, it is necessary to explore them in an environment that is as close to that likely to exist in the medium term as we can achieve. Such a solution would offer similar economic benefits to the current market in pollution tokens in the USA, which leads to incentives to innovate in clean power production. Similarly, we would expect services to be deployed in a wireless world that would maximise *both* innovation, and spectrum efficiency.

1.2 Environment

This section contains a description of the environment that we believe will exist in the medium term and at which we are targeting our proposal.

1.2.1 System architecture:

Current mobile systems fall into one of two categories. Cellular-like systems rely on a central base station to which all hosts within a given geographical area connect. On the other hand, ad-hoc systems are used wherever no fixed infrastructure is available - each host acts both as an endpoint and as a router for other traffic in the network.

Although the majority of research in this area to date has fallen one or other side of this divide, we believe that the divide is artificial. There is nothing fundamental that makes two types of system mutually exclusive and it is perfectly possible to conceive of environments in which parts of the system are served by cellular connections, parts by ad-hoc connections, and parts by connections that are a mixture of ad hoc and cellular. Please note that in this context, the term 'cellular' is used quite loosely. So, for example, there is already a set of fledgling activities aimed at creating community wireless LANs, some of which have respectable coverage across cities (see e.g. `http://www.wlan.org.uk/operational_wlan_sites.html`).

In summary, whilst it is simpler to suppose that future systems will be restricted to single-level, single-technology architectures, this ignores the current reality, let alone that which is possible given advances in network interfaces. Consequently, we believe that any practical generic mechanism aimed at a deregulated market must have within it the ability to take account of the existence of multi-level multi-technology wireless systems.

1.2.2 Technology:

Software radio has been an item of interest for several years now. Essentially, software radio moves as much of the modulation and demodulation of radio frequency (RF) signals into software as is possible, the limiting factor being the speed of the processor available. The advantage of this approach is that, by a simple change the software component, different modulation schemes and MAC protocols can used. Since affordable processors are now reaching speeds that allow software radio to be used for gigahertz frequency bands, it is clearly a technology that gives maximum flexibility and extensibility; a single network interface may be used to work with several different networking technologies.

We believe the adoption of software radio technology to be inevitable in the medium term, both because of commercial drivers - one network interface to satisfy personal area, local area, and wide area needs - and because it is ideal for use in a system where the allocation of spectrum to any given user group may change in response to changes in the secondary market envisaged by the FCC.

1.2.3 Modulation schemes:

The era of pure TDMA/FDMA is past. The modulation scheme of choice for the future is CDMA, though it is clear that older technologies will continue to persist because of the installed base. In an era of deregulation, and an environment in which parts of the network are multihop and parts are not, there is a problem with charging. If a base station is used in a single hop network to connect to some wider network infrastructure, it can act as a point that gathers information used in charging (regardless of whether it is credit-based or micropayment-based). If that single point of contact is subsumed in a more general environment, this charging model becomes too simplistic. Indeed, since one feature of CDMA is that concurrent users are indistinguishable from noise, it is clear that even strict policing is no longer possible.

So, how will this deregulated system work? There are several factors that come in to play:

- Users must purchase access rights. This process naturally involves a specification of what those rights are.

- In the main, the largest users will be located in metropolitan centres, which is where the bulk of competition for resources will occur. Software radio can work for the policing authorities; within a relatively small area, a spread of low-cost software radio components can be programmed to intercept traffic using the parameters specified in the original contract. If there is a discrepancy, action can be taken and, if the penalties are sufficiently severe and the likelihood of being caught sufficiently great, compliance can be assured.

- As above, it is hard to determine in-band whether users are utilising access rights for which they have not registered. However, for this to cause a significant problem, either there must be a significant number of users or a significant amount of traffic from a small number of users. The former can be deterred by good intelligence, the latter by broadband DF techniques.

1.2.4 Active networks:

Given the programmable aspects of the architectures we have described above, there is clearly considerable flexibility in the ways any given network can be realised. When multiple cooperating virtual networks are overlaid in the same physical space, using some network elements in common, it is clear that control over the form of network will be needed in a way that is sufficiently agile to respond to changing network conditions, but sufficiently stable to ensure that control traffic remains a small proportion of the overall traffic. In other words, it will be necessary to construct a meta-network using a distributed form of intelligence. Active network solutions are an ideal basis for this.

2 Proposed Solution

Given the appropriate technology, the key to this system is the accurate specification of access rights. We do not believe that constraining users into a limited set of predefined rights is consistent with the spirit of deregulation. Instead, we believe that a generic mechanism is strongly desirable; using this, different user communities can specify their requirements with a reasonable degree of precision. However, herein lies significant complexity. It is already obvious from Internet traffic models and PCS service models that new networks have quite different source models, traffic metrics and time of day variation. In our case, physical distribution and movement patterns are also an important issue, since they affect both routing and frequency reuse. Two groups of users, each requiring 2 Mbit/s at 4pm on alternate Fridays, may or may not perceive the level of service they require if a significant proportion of the participants in those groups share the same physical space, depending on local network provisioning.

In order to realise a secondary market, it is necessary to communicate use policies using some common framework. In the system we envisage, a "bourse" is used to communicate set of use policies and an outline description of the types of topologies the intended set of users will adopt. This allows bidding for the relevant spectrum and code division or other scheme to use it. In fact, again, there is a significant problem here - the issue of pricing. Given that we can create a flexible framework for the description of usage patterns, we need two further mechanisms:

1. A mechanism for determining whether a set of such descriptions will be satisfied by the actual level of network provision. Note that, because we would specifically like to include multi-hop networks, the outcome of this consideration is recursively dependent on the candidate set of descriptions chosen, in addition to the state of the fixed portions of the network. Put simply, the tension is between increasing the number of nodes in the system and their geographical dispersity in order to achieve maximal coverage, versus increasing the traffic in the system and introducing a form of thrashing at a communications level.

2. It must be possible to combine multiple descriptions to produce a unified description within the same description space. To see this, consider what happens if two user groups relinquish their allocations.

   (a) It would be possible to resell both allocations (or refinements of them), but that presumes that there would be an efficient market in such cast-offs. The more precision one allows in specifications in order to achieve maximal spectrum efficiency (and greatest return), the less likely it is that there would be a buyer willing to take on precisely that specification.

   (b) One could combine and then resplit the allocations in the most cost effective way possible. This would lead to a better solution than above, but one that was still globally suboptimal, since not only part of the overall spectrum allocation was considered. There are analogues in the financial markets. For example, mortgage bonds can be split into capital and interest parts and recombined into instruments with capital and interest parts from different mortgages.

   (c) Reallocate from scratch. In other words, completely resell the entire spectrum to an optimal set of bidders without consideration of the previous state of the system. No business could operate with this degree of uncertainty; licenses must persist for a sufficient period of time that the business investment in utilising the system has a very good chance of being recovered before the end of the licence period. Between the time that a company decides that it does not wish to retain its spectrum and the end of the licence period, that company should be free to resell its allocation, and the most effective way of doing this is to allow (b) above.

Finally, the mechanism of selling must be defined. Again, this is non-trivial. For example, it may be the case that, in order to match a potential purchaser's requirements, they must simultaneously buy a set of different allocations from a range of vendors, as opposed to purchasing one item at a time in the hope that eventually sufficient coverage may be obtained. In such a case we have what is known as a combinatorial auction[1]

?????? We could also do something like use the active nets part to sell spectrum on a short timescale temporary basis to nodes in the neighbourhood. In other words, we have a bourse for long term 'reservation' and bilateral agreements for short term fine tuning of this (and ability to realise revenue for unused spectrum). ???????

Once the precise provisioning is decided, then deployment of the system is achieved by having the appropriate (latest) modulation software downloaded to the set of stations, with larger-scale policing as discussed above.

3 Workpackages

This is a challenging project, requiring close cross-disciplinary cooperation in a number of areas.[1]. We believe that, in view of the FCC timescales, it is equally important to explore the theoretical and practical aspects of producing an efficient secondary market in spectrum. Consequently, we propose to investigate the following areas:

1. Scenario definition

   In order evaluate the solutions we propose, it is necessary to devise and agree appropriate scenarios against which the solutions will be tested. Note that, of themselves, such scenarios are a useful contribution to knowledge.

2. Usage policy specification

   A starting point for this work will be the recent work performed on power-law relationships within the Internet. This work is not sufficiently expressive to encompass the types of policy we envisage - consequently, we need to explore to what extent it is applicable and what the alternatives are..

3. Auctioning and reselling

   Combinatorial auctions (or somesuch) for longer-term spectrum reservation. Short timescale bilateral stuff for cooperative exchange of bandwidth with remuneration (doesn't preclude a third party acting as a broker - i.e. DAG of bourses).

4. Active networks

   Platforms for resource allocation will need to provide efficient accounting, as well as being secure and programamble. Xenoservers appear to fit this bill nicely.

References

[1] "Combinatorial auctions: A survey" S. DeVries and R. Vohra, 2000, `citeseer.nj.nec.com/devries01combinatorial.html`

[2] "Towards an Active Network Architecture", D. L. Tennenhouse and D. J. Wetherall, ACM Computer Communication Review, vol. 26, no. 2, pp. 5–18, Apr. 1996.

[3] Application Level Active Networks Michael Fry and Atanu Ghosh, UTS, in Computer Networks and ISDN Systems, `http://dmir.socs.uts.edu.au/projects/alan/papers/cnis.ps`

[4] Ghosh, Fry & Crowcroft, "An Architecture for Application Layer Routing", Yasuda, H. (Ed), Active Networks, LNCS 1942, Springer, pp 71-86. ISBN 3-540-41179-8 Springer-Verlag

[1]We note that the recent International Review of UK Computer Science research recommended this mode of research as a priority

[5] Elan Amir, Steven McCanne and Randy Katz, "An Active Service Framework and its Application to Real-time Multimedia Transcoding," ACM Computer Communication Review, vol. 28, no. 4, pp. 178–189, Sep. 1998

[6] M. Mathis, J. Semke, J. Mahdavi, and T. Ott. "The macroscopic behaviour of the TCP congestion avoidance algorithm." ACM Computer Communication Review, 27(3), July 1997.

[7] Jitendra Padhye, Victor Firoiu, Don Towsley and Jim Kurose, "Modeling TCP Throughput: A Simple Model and its Empirical Validation," ACM Computer Communication Review, vol. 28, no. 4, pp. 303–314, Sep. 1998.

[8] An End-to-end Rate-based Congestion Control Mechanism for Realtime Streams in the Internet R. Rejaie, M. Handley, D. Estrin. Proc. Infocom 99 `http://www.aciri.org/mjh/rap.ps.gz`

[9] New Internet Routing (a.k.a nimrod) `http://ana-3.lcs.mit.edu/ jnc/nimrod/docs.html`

[10] Paul Francis PhD thesis, UCL 1992. `ftp://cs.ucl.ac.uk/darpa/pfrancis-thesis.ps.gz`

[11] Curtiz Villamizar, Work in progress, i-d - ftp from http://www.ietf.org/ietf `draft-ietf-ospf-omp-02.txt`

[12] Multicast Inference of Network Congestion (minc) `http://gaia.cs.umass.edu/minc`

[13] RTP Quality Matrix `http://www-mice.cs.ucl.ac.uk/multimedia/software/rqm/`

[14] Self Organising Transcoders (sot) Isidor Kouvelas et al NOSSDAV 1998 ftp://cs.ucl.ac.uk/darpa/sot.ps.gz

[15] Receiver Driven Layered Congestion Control (a.ka. rlc) `ftp://cs.ucl.ac.uk/darpa/infocom98.ps.gz` and `ftp://cs.ucl.ac.uk//darpa/rlc-dps.ps.gz`

[16] Dynamic Distance Maps of the Internet Wolfgang Theilmann (University of Stuttgart), Kurt Rothermel (University of Stuttgart) Proceedings of IEEE Infocom 2000.

[17] A Network Measurement Architecture for Adaptive Applications Mark Stemm (University of California at Berkeley), Srinivasan Seshan (IBM T.J. Watson Research Center), Randy H. Katz (University of California at Berkeley) Proceedings of IEEE Infocom 2000.

[18] Scalable, Low-Overhead Network Delay Estimation Volkan Ozdemir (North Carolina State University), S. Muthukrishnan (ATT Labs - Research), Injong Rhee (North Carolina State University)

[19] Multicast Inference of Packet Delay Variance at Interior Network Links Nick Duffield (ATT Labs - Research), Francesco Lo Presti (ATT Labs - Research and University of Massachusetts)

[20] YALLCAST arhictecture, Paul Francis http://www.aciri.org/yoid/docs/index.html

[21] David Wetherall, Ulana Legedza and John Guttag, "Introducing New Internet Services: Why and How," IEEE Network, vol. 12, no. 3, pp. 12–19, May 1998.

[22] Maria Calderon, Marifeli Sedano, Arturo Azcorra and Cristian Alonso, "Active Network Support for Multicast Applications," IEEE Network, vol. 12, no. 3, pp. 46–52, May 1998.

[23] D. Scott Alexander, William A. Arbaugh, Michael W. Hicks, Pankaj Kakkar, Angelos D. Keromytis, Jonathan T. Moore, Carl A. Gunter, Scott M. Nettles and Jonathan M. Smith, "The SwitchWare Active Network Architecture," IEEE Network, vol. 12, no. 3, pp. 27–36, May 1998.

[24] A. Montz, D. Mosberger, S. O'Mealley, L. Peterson, T. Proebsting and J. Hartman, "Scout: A Communications-Oriented Operationg System," Department of Computer Science, The University of Arizona, no. 94-20, 1994.

[25] John Hartman, Larry Peterson, Andy Bavier, Peter Bigot, Patrick Bridges, Brady Montz, Rob Piltz, Todd Proebsting, and Oliver Spatscheck. " Joust: A Platform for Communications-Oriented Liquid Software ", IEEE Computer 32, 4, April 1999, 50-56.

[26] Quality of Service Filters for Multimedia Communications Nicholas Yeadon Ph.D. Thesis, Computing Department, Lancaster University, Bailrigg, Lancaster, LA1 4YR, U.K., May 1996. Internal report number MPG-96-35.

[27] "A Note on Power-Laws of Internet Topology," Hongsong Chou, Harvard University, Cambridge, Massachusetts, arXiv Technical report 0012019, Dec. 2000.

[28] Alberto Medina, Ibrahim Matta and John Byers, "On the Origin of Power Laws in Internet Topologies," ccr, vol. 30, no. 2, Apr. 2000.

[29] Rka Albert, Hawoong Jeong and Albert-Lszl Barabsi, "Error and attack tolerance of complex networks," Science, vol. 406, pp. 378–382, Jul. 2000.

[30] L. A. Adamic, R. M. Lukose, A. R. Puniyani and B. A. Huberman, "Search in Power-Law Networks," arXiv, arXiv Technical report cs/0103016, Mar. 2001.

[31] Amy Friedlander, ""In God We Trust" All Others Pay Cash," Washington, D.C., Dec. 1996.

[32] Daniel Zappala. Alternate Path Routing for Multicast. In Proceedings of the IEEE Infocom, March 2000. A Expansion in the Internet: Exponential or Power Law?

[33] "On Power-Law Relationships of the Internet Topology". Michalis Faloutsos, Petros Faloutsos, Christos Faloutsos, ACM SIGCOMM'99.

[34] Srikathyayani Srikanteswara, Jeffrey H. Reed, Peter Athanas and Robert Boyle, "A Soft Radio Architecture for Reconfigurable Platforms," ieeecm, vol. 38, no. 2, pp. –, Feb. 2000.

[35] Subir Biswas and Andy Hopper, "A Representative Based Architecture for Handling Mobility in Connection Oriented Radio Networks," Olivetti Research Laboratory (ORL), Cambridge, England, Technical Report TR 95-9, 1995.

[36] V. Bose, A. B. Shah and M. Ismert, "Software Radios for Wireless Networking," in infocom, (San Francisco, California), pp. 1030, March/April 1998.

[37] Ricardo J. Sanchez, Joseph B. Evans, Gary J. Minden, Victor S. Frost and K. Sam Shanmugan, "RDRN: A Prototype for a Rapidly Deployable Radio Network," mc2r, vol. 2, no. 2, pp. 15–22, Apr. 1998.

[38] Joseph Mitola, "Software Radio Architecture: A Mathematical Perspective," ieeejsac, vol. 17, no. 4, pp. 514–538, Apr. 1999.

[39] Thierry Turletti, Hans J. Bentzen and David Tennenhouse, "Toward the Software Realization of a GSM Base Station," ieeejsac, vol. 17, no. 4, pp. 603–612, Apr. 1999.

[40] Vanu Bose, Michael Ismert, Matt Welborn and John Guttag, "Virtual Radios," ieeejsac, vol. 17, no. 4, pp. 591–602, Apr. 1999.

[41] Peter G. Cook and Wayne Bonser, "Architectural Overview of the SPEAKeasy System," ieeejsac, vol. 17, no. 4, pp. 650–661, Apr. 1999.

[42] Joseph Mitola and Jr. Gerald Q. Maguire, "Cognitive Radio: Making Software Radios More Personal," ieeepcm, vol. 6, no. 4, pp. –, Aug. 1999.