Workshop on Applications of Radio Science (WARS '95)
25–27 June 1995, Canberra, Australia

Designing The Ubiquitous Microcellular Network

Brendan C. Jones and David J. Skellern

Electronics Department
School of Maths, Physics, Computing and Electronics
Macquarie University NSW 2109 Australia

email: brendan@mpce.mq.edu.au, daves@mpce.mq.edu.au

Abstract

This paper summarises the cell design issues for microcellular networks and explains how conventional large cell network design techniques may not be suitable for designing a ubiquitous microcellular network.

A general interference model developed for arbitrary microcellular networks, using a parameter denoted the 'interference to noise ratio' or INR, is used to determine the microcell spacing required to maintain certain cell coverage targets as a function of mutual spill power.

It is shown that a contiguous cell coverage requirement imposes significant limits upon the accumulated interference allowable in a microcell system.

0 Introduction

The popularity of mobile telecommunications has grown remarkably since the first commercial mobile cellular telecommunications service was launched in Chicago in October 1983.

As the user base grew, the capacity of the cellular system had to be increased. The advantage of cellular radio systems is that capacity can be increased by splitting existing cells into smaller cells and thus reuse frequencies more often in the one geographic area.

However, in practice there are limitations to the extent to which cells can be physically reduced in size. The public demand for mobile telecommunication services has grown to such an extent that in many large cities the capacity limits of existing cellular systems are beginning to be reached.

To meet future demand, and the vision of a personal communicator in every pocket, microcellular architecture was developed. Microcells differ from conventional cells in three fundamental ways:

- The cells are typically less than 1 km in radius
- The mobile terminals radiate much smaller power levels
- There is no centralised, fixed cell planning (all channels are available in every cell)

A ubiquitous microcell network of the future will need to satisfy certain requirements in order to be successful [1]:

- Low cochannel interference (< 1% of users)
- Closer frequency reuse
- Large percentage coverage (> 99%)

In the future, people will not accept poor call quality simply because the service is 'mobile' [2] but will demand a similar grade of service to that experienced in wireline services [3].

Thus, the wide scale deployment of an extensive, high grade, wireless telephone system will require engineering tools and techniques that allow rapid and accurate system design. The fundamental problem that needs to be addressed is of modelling the end result of multiple users propagating in a congested area [3],[4].

There does not yet appear to be a systematic design methodology for engineering a ubiquitous microcellular network to meet the service quality goals of good call quality, high efficiency, and wide reliable coverage [2]–[5]. The system design issues need to be examined.

1 Microcell System Design Issues

The applicability of conventional cellular design techniques to microcellular networks is questionable.

Firstly, the regular cell structures that can be used in large cell systems lead to a simple relationship between the cluster size C and the S/I, but no such simple relationship for C exists in microcells [6]. Microcells often overlap and become irregular in shape due to interference from other users [7], and interference control via Dynamic Channel Allocation (DCA) can still fail under heavy traffic loads [8].

Secondly, it has been shown that adjacent channel interference (ACI) can affect the performance of heavily loaded large cell systems [9]–[11] and it may be even more important in microcells [12].

Thirdly, the close spacing of base stations in microcellular systems (especially in multioperator environments), higher frequency reuse, and spatial traffic variability have a significant impact upon the proportion of service area that has a circuit quality better than some specified value [1],[7],[13]–[15].

These factors may make it very difficult to engineer a microcell system so that reliable, contiguous radio coverage is achieved for a given proportion of mobile terminals. It has been suggested that contiguous coverage may be impossible to achieve [16],[17].

To move forward, a model is needed that can describe the cumulative interference effects of all users in an arbitrary cellular network, and that enables a uniform analysis from noise to interference limited environments. Both thermal noise and propagated interference need to be considered because the transmission quality is strongly dependent upon these two factors [18].

2 Microcell Interference Model

To consider the factors that may influence how a microcell network can be laid out to provide reliable coverage, the single interferer analysis presented in [19] will be extended to analyse a pair of interferers as shown in figure 1 below.

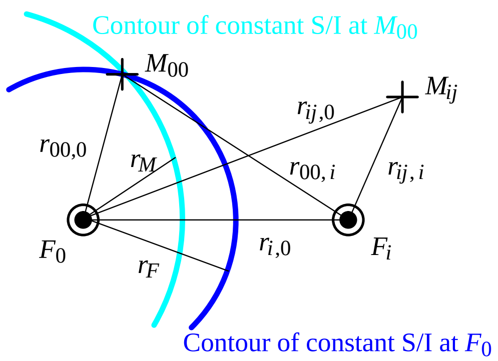

Figure 1 – A mobile link operating in the presence of an interferer pair

Figure 1 shows a mobile terminal M_{00} attempting communication with a fixed station F_0 at a range $r_{00,0}$ in the presence of a mobile–fixed station interferer pair F_i and M_{ij}, at ranges from F_0 and M_{00} as indicated. Both M_{00} and F_0 transmit the wanted signal at a power P_t. F_i spills an interference power P_u into the wanted uplink (M_{00} to F_0) and M_{ij} spills an interference power P_d into the wanted downlink (F_0 to M_{00}).

For analytical tractability a simple distance–dependent propagation model is used [19]:

$$P_{rx} = \kappa P_{tx} d^{-\gamma} \tag{1}$$

where P_{tx} is the transmitted power, P_{rx} is the average power received at a distance d from the transmitter, κ is an RF factor and γ is the path loss exponent.

In order for the mobile M_{00} to successfully establish a link with F_0, the S/[N+I] at M_{00} and at F_0 both need to be greater than or equal to the system protection ratio Z else an 'outage' occurs.

Following the outage contour derivations in [19], it can be shown that the uplink outage contour for the wanted link is given by:

$$r_F^{\gamma} = K_u \, r_{ij,0}^{\gamma} \left[\frac{\eta_F}{\eta_F + 1} \right] = \psi \left[\frac{1}{\eta_F + 1} \right] \tag{2}$$

and the downlink outage contour is given by

$$r_M^{\gamma} = K_d \, r_{00,i}^{\gamma} \left[\frac{\eta_M}{\eta_M + 1} \right] = \psi \left[\frac{1}{\eta_M + 1} \right] \tag{3}$$

where $K_u = P_t/ZP_u$ for the uplink, $K_d = P_t/ZP_d$ for the downlink, and $\psi = \kappa P_t/ZN$. The uplink 'interference to noise ratio' or INR [19] for the scenario in figure 1 is given by:

$$\eta_F = \frac{\kappa P_u \, r_{ij,0}^{-\gamma}}{N} \tag{4}$$

and the downlink INR is given by:

$$\eta_M = \frac{\kappa P_d \, r_{00,i}^{-\gamma}}{N} \tag{5}$$

3 Contiguous Cell Coverage

Consider that the two mobile terminals in figure 1 move towards each other on the line joining F_0 and F_i, remaining equidistant from their respective fixed stations (i.e. $r_{00,0} = r_{ij,i}$), until each mobile terminal's link fails. The terminal range at outage then represents the worst–case proximity between these mobile terminals in neighbouring cells.

To simplify the notation for this situation, the separation between the fixed stations F_i and F_0 ($r_{i,0}$) will be denoted S. Using the parameter α ($0 \le \alpha \le 1$) the range of the mobile terminals can then be written as $r_{00,0} = r_{ij,i} = \alpha S$ and $r_{00,i} = r_{ij,0} = (1–\alpha)S$.

Conditions can be attached to the relative outage range α of the mobile terminals in order to achieve certain cell coverage goals, such as contiguous or near contiguous coverage.

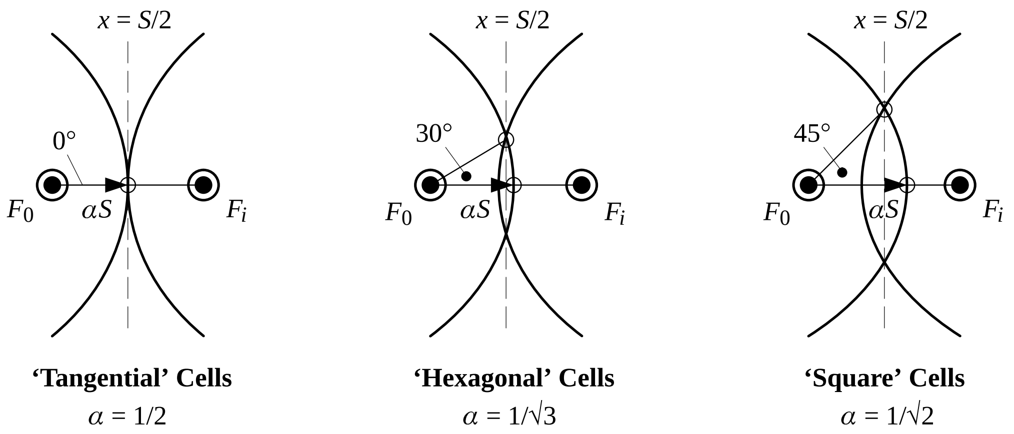

Figure 2 – Three types of cell arrangements

Three such goals are illustrated in figure 2 above: 'tangential' cell coverage, 'hexagonal' cell coverage, and 'square' cell coverage. Each provides progressively greater cell overlap. These goals represent a terminal range at outage of $S/2$, $S/\sqrt{3}$ and $S/\sqrt{2}$ respectively (i.e. $\alpha = 1/2$, $1/\sqrt{3}$ and $1/\sqrt{2}$ respectively).

If it is assumed that the channel spills are symmetrical between the mobile–fixed station pairs then $P_u = P_d = P_s$, the mutual spill power. Thus $K_u = K_d = K$, and substituting αS for r_F and $(1–\alpha)S$ for $r_{ij,0}$ in the ψ form of equation (2) and solving for S gives:

$$S = \frac{1}{\alpha}\left\{\frac{\kappa P_t}{N}\left(\frac{1}{Z} - \frac{P_s}{P_t}\left[\frac{\alpha}{1-\alpha}\right]^{\gamma}\right)\right\}^{1/\gamma} \qquad (6)$$

Equation (6) defines the worst–case fixed station separation S required to achieve cell overlap to the extent defined by α, as a function of the relative mutual spill power P_s/P_t.

Equation (6) may be plotted for an actual microcell technology such as CT2. Figure 3 shows the base station separation required as a function of the relative mutual spill power P_s/P_t (expressed in dBr) to maintain the three cell arrangements as shown in figure 2.

Figure 3 shows that a contiguous cell coverage requirement demands smaller and smaller base station separations as the relative mutual spill power increases. The reduction in base station separation becomes extremely rapid near the 'waterfall' part of each curve, and ultimately contiguous coverage becomes impossible once the spill power exceeds a certain value.

As a microcell network becomes more highly interference limited, mobile links in that network will operate more frequently near the waterfall part of the curves in figure 3. Small amounts of additional interference will then greatly reduce the quality of cell coverage possible for those susceptible mobile links.

Thus a contiguous coverage requirement imposes significant limits upon the accumulated interference allowable in a microcell system, and when those limits are exceeded, the proportion of mobile terminals that experience below target cell sizes will begin to grow. This could have severe ramifications upon the quality of cell coverage and the handoff reliability and thus the offered service quality.

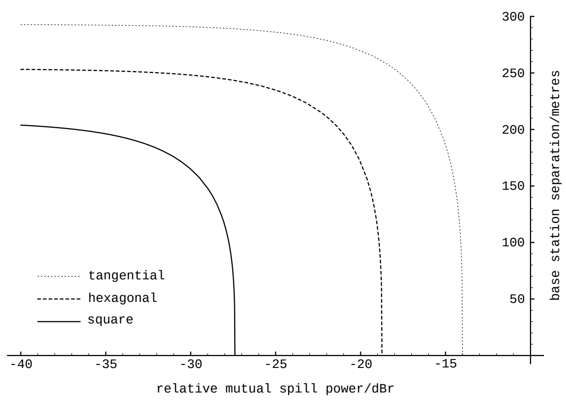

Figure 3 – CT2 base station separation vs relative mutual spill power (γ = 3.5, P_t = 10 dBm)

4 Conclusion

By using a general interference model developed for arbitrary microcellular networks, and a parameter denoted the 'interference to noise ratio' or INR, the microcell spacing required to maintain certain cell coverage targets as a function of mutual spill power was derived for an interferer pair.

It was shown that a contiguous cell coverage requirement imposes significant limits upon the accumulated interference allowable in a microcell system. This will need to be considered if an engineering methodology is to be developed to enable the design of a ubiquitous microcellular network.

5 References

[1] D.C. Cox: "Wireless Network Access for Personal Communications", *IEEE Communications Magazine*, pp 96–115, Dec 1992.

[2] I. Goetz: "Transmission Planning for Mobile Telecommunication Systems", *6th IEE International Conference on Mobile Radio and Personal Communications*, pp 126–130, Coventry, UK, 9–11 Dec 1991.

[3] J. Sarnecki, C. Vinodrai, A. Javed, P. O'Kelly, K. Dick: "Microcell Design Principles", *IEEE Communications Magazine*, vol 31 no 4 pp 76–82, April 1993.

[4] T.S. Rappaport: "Wireless Personal Communications: Trends and Challenges", *IEEE Antennas and Propagation Magazine*, vol 33 no 5 pp 19–29, Oct 1991.

[5] A. Gamst, "Remarks on Radio Network Planning", *Proceedings of the 37th IEEE Vehicular Technology Conference*, p. 164, Tampa, 1–3 June 1987.

[6] W.T. Webb: "Modulation Methods for PCNs", *IEEE Communications Magazine*, vol 30 no 12 pp 90–95, Dec 1992.

[7] D. Everitt, D. Manfield: "Performance Analysis of Cellular Mobile Communications Systems with Dynamic Channel Assignment", *IEEE Journal on Selected Areas of Communications*, vol 7 no 8 pp 1172–1180, Oct 1989.

[8] P.T.H. Chan, M. Palaniswami and D. Everitt: "Dynamic Channel Assignment for Cellular Mobile Radio System using Self–Organising Neural Networks", *6th Australian Teletraffic Research Seminar*, pp 89–95, Wollongong, Australia, 28–29 Nov 1991.

[9] S.W. Wang, S.S Rappaport: "Signal to Interference Calculations for Balanced Channel Assignment Patterns in Cellular Communications Systems", *IEEE Transactions on Communications*, vol 37 no 10 pp 1077–1087, Oct 1989.

[10] J.P. Driscoll: "Relevance of Receiver Filter Performance and Operating Range for CT2/CAI Telepoint Systems", *Electronics Letters*, vol 28 no 13 pp 1200–1201, 18 June 1992.

[11] J.P. Driscoll: "Some Factors Which Affect the Traffic Capacity of a Small Telepoint Network", *5th IEE International Conference on Mobile Radio and Personal Communications*, pp 167–71, Coventry, UK, 11–14 Dec 1989.

[12] S–W. Wang, S.S. Rappaport: "Signal to Interference Calculations for Corner Excited Cellular Communications Systems", *IEEE Transactions on Communications*, vol 39 no 12 pp 1886–1896, Dec 1991.

[13] A.O. Fapojuwo, A. McGirr, S. Kazeminejad: "A Simulation Study of Speech Traffic Capacity in Digital Cordless Telecommunications Systems", *IEEE Transactions on Vehicular Technology*, vol 41 no 1 pp 6–16, Feb 1992.

[14] P.A. Ramsdale, A.D. Hadden, P.S. Gaskell: "DCS1800 – The Standard for PCN", *6th IEE International Conference on Mobile Radio and Personal Communications*, pp 175–179, Coventry, UK, 9–11 Dec 1991.

[15] S. Sato, K. Takeo, M. Nishino, Y. Amezawa, T. Suzuki: "A Performance Analysis on Nonuniform Traffic in Microcell Systems", *IEEE International Conference on Communications* (ICC 93), vol 3 pp 1960–1964, Geneva, Switzerland, 23–26 May 1993.

[16] S.T.S. Chia: "The Universal Mobile Telecommunication System", *IEEE Communications Magazine*, vol 30 no 12 pp 54–62, Dec 1992.

[17] S.T.S. Chia: "Providing Ubiquitous Cellular Coverage for a Dense Urban Environment", *44th Vehicular Technology Conference*, pp 1045–1049, Stockholm, Sweden, 8–10 Jun 1994.

[18] A. Kegel, W. Hollemans, R. Prasad: "Performance Analysis of Interference and Noise Limited Cellular Land Mobile Radio", *41st IEEE Vehicular Technology Conference*, pp 817–821, St Louis, USA, 19–22 May 1991.

[19] B.C. Jones and D.J. Skellern: "Interference Modelling and Outage Contours in Cellular and Microcellular Networks", *2nd MCRC International Conference on Mobile and Personal Communications Systems*, pp 149–158, Adelaide, Australia, 10–11 April 1995.