# A DCA ALGORITHM FOR INDOOR PERSONAL COMMUNICATIONS

R C Atkinson & J Dunlop
University of Strathclyde
204 George Street
Glasgow, Scotland, UK
G1 1XW
Email: robert.atkinson@ieee.org

## Abstract

This paper proposes the implementation of a combined DCA and call admissions control policy on indoor picocellular base stations to provide increased capacity whilst maintaining a 'fair' QoS (Quality of Service) for users on each base station.

## 1 Introduction

Extending 3G coverage to the indoor area is attractive for two key reasons. Firstly, it allows ubiquitous coverage and possibly the provision of seamless handover between indoor and outdoor environments. Two approaches can be taken:

- Indoor cellular base stations operating as conventional cellular sites; allowing handover to and from other cells
- An alternative approach involves the indoor base stations operating as a hybrid cellular-cordless system; handover is permitted to a set of 'approved' base stations (BSs). The set of BSs includes the indoor BSs owned by a single customer. This provides coverage throughout a building. Additionally the set may include exterior BSs; this allows seamless indoor-outdoor coverage.

Secondly, there is also the drive to introduce advanced services that require higher bit-rates; multi-media services. It is anticipated that multi-media services (e.g. web browsing, video telephony) are more likely to be demanded by slow moving users or those located *indoors*. This points to the need for large and flexible bandwidth provision for indoor communication systems.

The cordless technology DECT has been deployed in Europe for a number of years. It operates in the 1880-1900 MHz frequency band, and therefore avoids co-channel interference with cellular systems that operate in the 890-960 MHz and 1710-1880 MHz bands. However due to the growing demand for ubiquitous coverage; seamless indoor-outdoor coverage and provision of high bit-rate services, cellular operators are now looking to extend their network coverage to the indoor arena. The spectrum allocated in Europe for indoor use (currently allocated to DECT) may not be sufficient to cope with the expected demand for both voice and multi-media traffic. This presents the need for increased spectrum for indoor use and for greater spectrum efficiency therein.

Increased spectrum can be achieved in a number of ways: allocation of previously unused 'new' spectrum (via spectrum auctions, for example), allocation of spectrum already allocated for external coverage, or share spectrum with other systems (DECT, PHS, wireless LANs). These are mainly political considerations and are outwith the scope of this research. Nonetheless, the need remains to provide increased spectrum efficiency, and that is the focus of this paper.

In the indoor arena it is desirable to allow indoor base stations to be installed in an uncoordinated fashion (i.e. no preplanning required). Sharing of radio resources (or spectrum) between base stations has the potential to provide greater system capacity than partitioning the available spectrum between them. If the spectrum is to be shared then a mechanism must exist to provide 'fair' access to the spectrum to users of all base stations. That is, one base station must not be allowed to monopolise the spectrum for its users and starving the users on other base stations of resources. This paper proposes such a scheme.

This paper first presents the problems associated with the provision of indoor radio capacity. It examines the scenario where picocellular base stations are deployed to provide interior coverage for voice and data communications. A DCA technique is examined that will support uncoordinated installation and coexistence with surrounding indoor base stations. Since future systems are likely to be packet-based, a DCA technique which operates in tandem with a packet access mechanism is proposed as a means of increasing the capacity of the available spectrum. It is shown that heavily loaded base stations can monopolise radio resource, resulting in resource starvation on other nearby base stations. A benevolent, priority-based, call admissions policy is operated which provides more uniform QoS across participating base stations.

## 2 Impact of Indoor Environment on Coverage

Partitioning of the radio spectrum between indoor base stations (i.e. FCA) may not be a viable option. Capacity in the external network is provided by exploiting the depreciation in signal strength over distance, enabling a limited number of channels to be re-used. Central to achieving this are: the positioning of BTSs in such a way as to form the cellular patchwork, and the assignment of physical channels to each of the cells. In the indoor arena, operators have less flexibility in the positioning of base station sites since inevitably they will have to be deployed within the building to which they will offer coverage. After all, it is unreasonable to expect that the proprietor of an establishment will be willing to allow the base station of his neighbour to be situated on his premises. The limited flexibility increases the difficulty of producing regular frequency reuse plans. Furthermore, the complexity of indoor propagation, resulting in rapid transitions in signal quality and strength due to obstacles etc., gives rise to the need for high transmission powers (up to 24dBm). The high transmission power would increase the range at which the channel can be reused, hence increasing the effective cluster size, if a FCA scheme is employed. Consequently if a number of indoor base stations were deployed at close proximity, the limited available spectrum combined with the factors outlined previously, would result in cells with relatively few channels and hence limited capacity.

Continual frequency planning is a necessary task of the external network, required to cope with changing traffic patterns. The major operators may re-plan their networks up to four times per year. This operation requires skilled personnel, is manpower intensive, and consequently expensive. A significant proportion of an operator’s costs can be attributed to the financial burden of repeated frequency re-planning. It is conceivable that the number of deployed indoor base stations will eventually exceed the current number of exterior base stations. If re-planning were required in the indoor arena whenever a new base station was deployed, the cost of re-planning the frequencies among the neighbouring base stations may prove prohibitive. The difficulty employing and FCA system indoors coupled with the financial burden on re-planning highlights the need for future systems to embrace the concepts of uncoordinated installation and coexistence for picocell sites.

## 3 Indoor-Outdoor Cellular Radio Coverage

Simulations have been conducted to assess the influence of signals from indoor base stations on the immediate vicinity [1]. It has been shown that signals from indoor base stations have the potential to illuminate surrounding streets and adjacent buildings. The implication of this research is that it may not be possible to use the same frequency bands in the indoor as well as the outdoor environments.

Further simulations were conducted which show that the effective coverage area of an indoor base station is limited to at most a few city-blocks. The simulations were conducted as follows. A model of a single storey city-block was constructed, consisting of eight buildings. An indoor base station is deployed in one of the buildings and can be viewed as a ground floor base station, as shown in Figure 1. Each building is composed of a number of walls, and the walls have an associated transmission loss factor (e.g. exterior walls have a loss factor of 15.62 dB). The loss factors are provided in [2]. Each building is square and has a single exterior door.

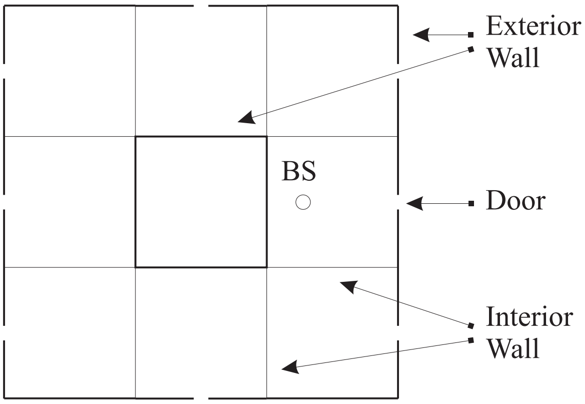

**Figure 1 : Urban City Block**

In order to estimate the range of influence of an indoor base station in a typical urban city centre, a matrix of identical city blocks (Manhattan Grid) was created, as shown in Figure 2. In this example a matrix of 5x5 city blocks is constructed, the block containing the base station is located at the centre, marked 'X'.

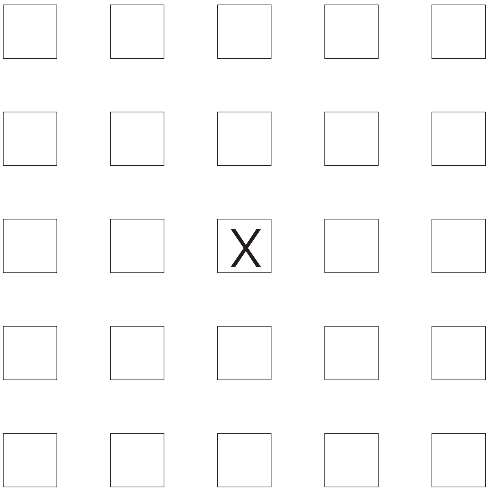

Figure 2 : Manhattan Grid Structure

The Motley Indoor Propagation Model [2] was used to predict the coverage area of the base station, an example plot is shown in Figure 3. The base station is deployed at (0,0) i.e. in the centre city block, Figure 1 shows the location of the base station within that city block.

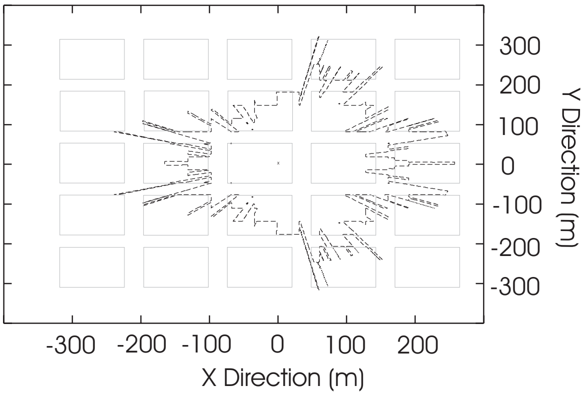

Figure 3 : Signal Footprint for Manhattan Grid

Figure 3 reveals that indoor base stations have the potential to cause interference with other indoor base stations only in the same or surrounding city-blocks, i.e. interference is generally restricted to at most a radius of a few city-blocks. From this information, it can be concluded that where indoor base stations are deployed they will interfere with only a limited number of other indoor base stations. Radio resource management algorithms may be able to take advantage of the fact that only a limited number of base stations will compete for the available spectrum.

# 4 The DCA Algorithm

Many DCA algorithms cannot be implemented in practice; often they are too computationally expensive or have the requirement for additional expensive infrastructure. Since it is the aim of this research to suggest practical solutions to the indoor capacity problem, simplicity and infrastructure cost will be important considerations in the selection of algorithms and techniques.

It is proposed that the need for additional infrastructure can be reduced if base stations communicate with each other over the air-interface. This negates the need for expensive fixed line connections between the base stations. Under this scheme, the base stations will broadcast channel occupancy data on a special bi-directional beacon channel. This research therefore assumes that base stations within a given radius will be heard by the considered base station. All base stations monitor the channel and refrain from transmitting on channels that are indicated as being occupied by a neighbouring base station. The rationale is that if two or more indoor base stations are close enough to interfere, then they can exchange signalling information and hence co-operate in the sharing of the available channels. If the base stations are sufficiently separated such that reception from a beacon channel is not possible then it will be more likely that the base station has no potential interferers and can therefore allocate channels unilaterally. This gives rise to the concept of isolated ‘pockets’ (that may form dca-nets) of indoor base stations that share the same channel-set, as shown in Figure 4. Furthermore, there would be sparse interconnection between neighbouring ‘pockets’. In this event the base stations can co-operate in the sharing of radio resources using a DCA algorithm.

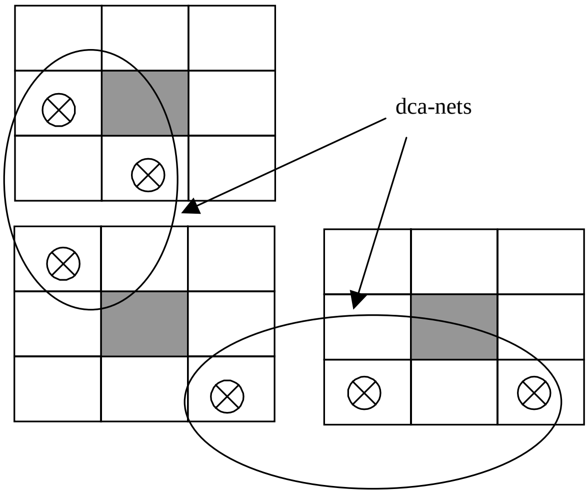

Figure 4: Two isolated dca-nets

The isolation of the ‘pockets’ of participating base stations and the limited number of members can be exploited to reduce the complexity of the DCA algorithm. It allows a simple DCA technique to be implemented. Since the number of members is limited, signalling over the air-interface is a viable option. The isolated nature of the pockets allows a *pure* DCA technique to be implemented. That is, all channels reside in a common pool and are can be allocated to a mobile-base station pair on an on-demand basis. When the channel is no longer required it may be returned to the pool, i.e. no channel borrowing is required. In this paper, pockets of participating base stations will be referred to as dca-nets.

Many proposed DCA algorithms employ some form of channel borrowing scheme. With channel borrowing schemes, a heavily loaded base station (acceptor) can borrow channels from other base stations (donors). There is a variety of algorithms that the acceptor BS can employ in the selection of the appropriate donor. The problem associated with such schemes is that under heavy load, the frequency reuse plan can become fragmented and hence non-optimal, this leads to a capacity reduction[3].

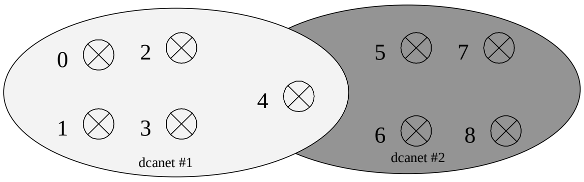

**Figure 5 : Two DCA-nets**

The pure DCA scheme is not without its disadvantages. The scheme was shown to exhibit non-uniform QoS (packet loss probabilities) on base stations that were members of more than one dca-net, as shown in Figure 5. A base station that is a member of two (multiple) dca-nets (multiple participant) must refrain from using channels used by the members of both dca-nets. Therefore it has a lower number of potential channels available at any particular time than members of a single dca-net. The result is an increase in packet loss probability (reduced QoS) due to radio resource starvation. Previous results [4] demonstrate that as the number of multiple participants of the same two dca-nets increases the unfairness decreases.

In order to increase the QoS on the few base stations that were members of multiple dca-nets, a large number of channels had to be allocated to the channel pool. This resulted in an increase in QoS across all members, i.e. the multiple participants still had considerably poorer QoS nonetheless all base stations were above the QoS threshold. However the increase in QoS is disproportionate to the number of additional channels required.

If access to radio resources could be made fairer then the multiple participants would have higher QoS values without the need for as many additional channels, i.e. the dca-nets would also become more spectrum efficient. The DCA scheme has been combined with the benevolent CAC scheme to provide ‘fairness’.

## 5 Provision of Fair radio access

In keeping with the concept of signalling between base stations via the air-interface, the benevolent CAC scheme assumes that all base stations in a dca-net transmit their current packet loss probability along with the previously mentioned channel occupancy data. The channels allocated to a dca-net are numbered incrementally, i.e. 1 to N, as shown in Figure 6. Each participating base station has an associated channel access priority, P, which allows access to channels 1 to P, and preventing access to channels P+1 to N. If a particular base station has a high blocking probability in relation to the others it increases its access priority, and base stations with a lower blocking probability reduce theirs. The result is a *self-organising* system whereby all members participate in dynamically adjusting their access priority, endeavouring to provide a uniform QoS across all members.

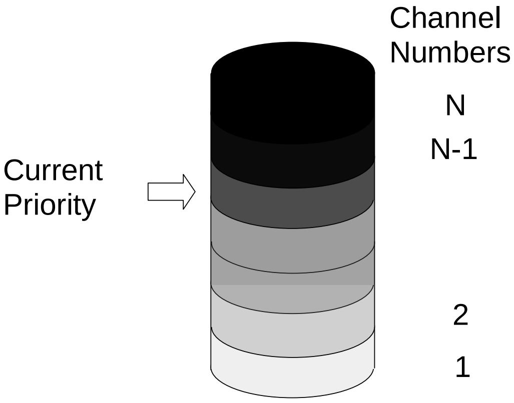

**Figure 6 : Priority Scheme**

Simulations have been conducted to predict the effect of applying the DCA algorithm on its own, and in conjunction with the benevolent call admissions control policy (termed fair dca). Circuit-switched traffic has previously been considered and is reported in [5]. However, since future systems are anticipated to be packet-based, a packet access mechanism was implemented. Carriers are divided into eight slots and packets can be transmitted in each slot. At the start of a transmission, mobiles contend for a slot; if successful the base station informs the mobile which slots it may transmit on in future. If unsuccessful the mobile waits a random (negative exponential) back-off period.

Packet loss probabilities were measured on all base stations to provide overall packet loss statistics as well packet loss variation across base stations for a particular load. The service type assumed is packet speech. This service is modelled through the conventional Poisson arrival process (mean varied to provide range of offered traffic) and negative exponential call duration distribution (of mean 156s). During calls, talkspurt (mean duration 1.2s) and silence periods (mean duration 1.8s) were modelled using the Brady on-off model. During each talkspurt speech frames were generated, decomposed into packets/bursts (four bursts per packet) and transmitted in slots. The procedure is described more fully in [6]. Applying the above procedure allows a packet speech service to be modelled.

The variation in QoS across participating base stations is depicted in Figure 7, with 95% confidence intervals. The plot shows that the fair scheme provides a more uniform QoS below 320 calls/h and above 500 calls/h. There is a noticeable deterioration in performance between these two values. Below the lower value the fair scheme is more able to adapt to nonhomogeneous traffic loads than the pure scheme. Above the higher value the increased traffic allows 'more recent' estimates of packet loss to be used in the fair scheme (due to large number of packets being received).

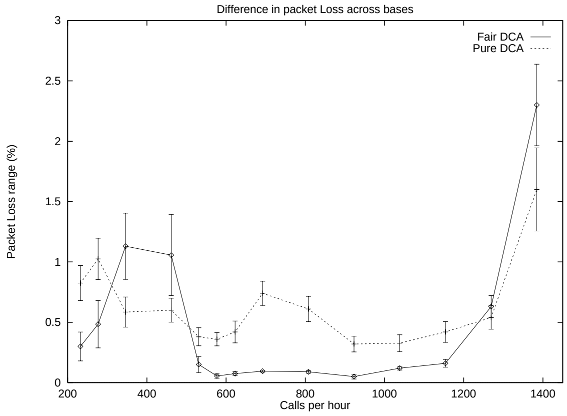

**Figure 7 : Difference of Packet Loss**

The relative reduction in packet loss obtained by implementing the benevolent CAC policy was calculated A paired-*t* confidence interval procedure [7] was used to place 95% confidence intervals on the estimate of improvement, as plotted in Figure 8. It can be seen the fair DCA scheme performs better than the pure scheme by reducing packet loss by over to 85% relative to the pure scheme in some instances. Again slight performance degradation can be seen between two similar values (320 - 500 calls/h) apparent on Figure 7.

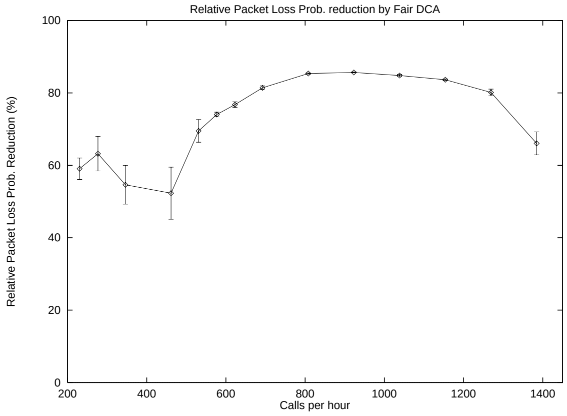

**Figure 8 : Packet Loss comparison of both schemes**

# 6 Signalling Requirement

Both techniques (pure and fair DCA) require signalling on a beacon channel and will be dependant on the update period of the algorithm. Packet loss probability is represented as a number between 0 and 100 in increments of 0.01. This information may be encoded by 14 bits. For a carrier with 7 traffic channels this requires 98 bits to represent the packet loss on each slot on the carrier. Assuming 1/4 rate coding (error control), 392 bits must be transmitted over the air-interface per carrier. The simulations conducted for this paper assumed an update period of 590.72 ms (every 128 frames), this requires signalling of 664 b/s per carrier.

# 7 Conclusions and Summary

It has been shown that a pure DCA technique is applicable to the indoor environment. Unlike the external environment radio signals are limited to at most a few city blocks. When nearby city blocks also contain indoor base stations, the channels are shared based on information gleaned from a broadcast signalling channel. Therefore the base stations will form small isolated groups; dca-nets. This structure allows a pure DCA technique to be implemented whereby all carriers reside in a common carrier pool.

Some members of a dca-net suffer from poorer QoS (i.e. significantly differences in packet loss probabilities) than others. Two reasons are identified for this:

1. Base stations that are members of more than one dca-net must share potential channels with more base stations than a base station that is a member of just one of the dca-nets.

2. Non-homogeneous traffic loads on participating base stations cause members with heavy load to monopolise the radio channels.

A priority-based benevolent call admissions policy is proposed that has the dual benefits of providing more uniform QoS across participating base stations, and reducing the overall packet loss probability.

## 8 Acknowledgements

The work reported in this paper has formed part of the Networks area of the Core I Research Programme of the Virtual Centre of Excellence in Mobile & Personal Communications, Mobile VCE, www.mobilevce.co.uk whose funding support is gratefully acknowledged. More detailed technical reports on this research are available to Industrial Members of Mobile VCE.

## 9 References

[1] Atkinson, R. C. & Dunlop, J., Potential for mobile coverage improvement in urban environments, Proc. ICUPC’98, Florence, Italy, October, 1998, pp. 9 – 13

[2] Gollreiter, R., Channel Models Issue 2, ATDMA Deliverable R2084/ESG/CC3/DS/P/029/b1, 1994, pp. 77-81

[3] Katzela, I. & Naghshineh M., Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey, IEEE Personnal Communications, June 1996, pp. 10 – 31

[4] Irvine, J., Atkinson, R., *et. al.*, Mobile VCE Core I Deliverable D31, MVCE/USC/N31/DS/I/020, March 2000

[5] Irvine, J., Le Bodic, G., Atkinson, R., Weerakoon, D., Fair resource management in diverse cellular systems, To be published, Proc. VTC 2000 Fall, Boston.

[6] Atkinson, R. C. & Dunlop, J., Comparison of ISMA and DECT-DCS channel access policies for indoor wireless communications systems, Electronics Letters, Vol. 36, No. 15, 20th July, 2000, pp.1307 – 1309

[7] Law, A. M. & Kelton, W. D., Simulation Modeling & Analysis, 2nd Edition, McGraw-Hill, pp. 587 – 588