Novel DCA algorithms for efficient Channel Assignment in Cellular Communications and their evaluation through a generic Java Simulation System

P.M.PAPAZOGLOU[1], D.A.KARRAS[2], R.C.PAPADEMETRIOU[3]
[1] Department of Informatics & Computer Technology
Lamia Institute of Technology, Greece
and University of Portsmouth
United Kingdom
[2] Department of Automation Engineering
Chalkis Institute of Technology, Greece
[3] Department of Electronic & Computer Engineering
University of Portsmouth, United Kingdom

Abstract - In recent years, mobile telephony, computing and services have emerged as an important field of research. The rapid evolution of cellular technology and the augmentative user demand for advanced mobile services leads the industry to develop more efficient network structures. The increasing number of cellular users and the demand for broadband mobile communications (3rd and 4th generation) drives to the research of new methodologies for the design of cellular networks and services. One of the issues in such a design is selection of channel allocation schemes. This paper thoroughly reviews centralized and mainly distributed DCA schemes and presents several new efficient variations suitable for large scale cellular systems. On the other hand, Simulation environments more than ever offer the opportunity to develop and study with low cost new structures and methods for the implementation of new services. To this end, this paper proposes a comprehensive simulation system for evaluating channel assignment schemes incorporating their principles, entities and concepts involved.

Key-words: - cellular network, simulation model, new channel allocation schemes, simulation environment

1 Introduction

1.1 The need of simulation systems for designing cellular networks

Using simulation systems, we can evaluate the performance and the behaviour of a real cellular network without the need to perform field experiments and develop prototypes. The simulation solutions offer the opportunity to develop channel allocation schemes, network structures, etc, towards to a desired cellular network. Due to the complexity of real cellular networks the simulation software development strategy becomes a very critical factor that influences the resulted network model. The challenge of wireless network simulation is finding the way to approach the real network behaviour and not just to speedup the execution time using parallel machines. The structure of the simulation environment affects the performance of simulated cellular network and for that reason we try to study the design and the development of such system. Many approaches to simulation systems have been made using various simulation languages. Languages such as Simula[1], Parsec[2], GPSS[3], Simscript[4], modsim[5], slam[6] and other of special purpose offer high flexibility for simulation systems development but introduce lack of portability and lag in terms of general purpose optimizations, etc. Other software tools like Matlab, have a plethora of libraries and capabilities for flexible script code development but suffer from low performance execution. A Large scale simulation system requires a high performance environment with advanced characteristics such as portability, internetworking, etc. The invention of new simulation languages introduce important drawbacks which are:

- New languages are domain-specific and are rarely adapted by scientific community
- The corresponding libraries impose the designers to adapt their applications in specific requirements
- Designers can not achieve high adaptability of the simulation kernel in their applications

Java language is the most suitable for building flexible, portable and high performance network applications and is adapted by the majority of scientific community. With this simulation program, we attempt to build a generic simulation system for cellular communication systems of 3rd towards 4th generation in order to perform simulations not in ad-hoc systems as most software tools do. With a generic simulation system, clear and general conclusions can be extracted compared to ad-hoc wireless networks.

1.2 The concept of cellular network

According to cellular principle the whole geographical coverage area is divided to smaller service areas called cell. A base station is placed in the center of each cell for servicing a number of mobile devices. The mobile device within a cell communicates through wireless links with the base station associated with the cell. A number of base stations are connected to the Base Station Controller (BSC) via microwave links or dedicated leased lines. The BSC is responsible for transferring an ongoing call from one base station to another as a mobile user moves from cell to cell. An allocated channel is released under two scenarios: the user completes the call or the mobile user moves to another cell before the call is completed.

1.3 A short overview of Channel Allocation schemes

The capacity of a cellular system can be described in terms of the number of available channels, or the number of users the system can support. The available frequency spectrum is limited and the number of mobile users is increasing day by day, hence the channels must be reused as much as possible to increase the system capacity. The assignment of channels to cells or mobile is one of the fundamental resource management issues in a mobile communication system. The role of a channel assignment scheme is to allocate channels to cells or mobiles in such a way as to minimize: a) the probability that the incoming calls are dropped, b) the probability that ongoing calls are dropped, and c) the probability that the carrier-to-interference ratio of any call falls below a prespecified value. In literature, many channel assignment schemes have been widely investigated with a goal to maximize the frequency reuse. The channel assignment schemes in general can be classified into three strategies: Fixed Channel Assignment (FCA) [7,8, 9,10,11], Dynamic Channel Assignment (DCA) [7,12,13,14,15], and the Hybrid Channel Assignment (HCA) [7,16]. In FCA, a set of channels are permanently allocated to each cell based on a pre-estimated traffic intensity. In DCA, there is no permanent allocation of channels to cells. Rather, the entire set of available channels is accessible to all the cells, and the channels are assigned on a call-by-call basis in a dynamic manner. To overcome the drawbacks of FCA and DCA, the HCA combines the features of both FCA and DCA techniques. DCA schemes can be implemented as centralized or distributed. In the centralized approach all requests for channel allocation are forwarded to a channel controller that has access to system wide channel usage information. I distributed DCA, the decision regarding the channel acquisition and release is taken by the concerned base station on the basis of the information from the surrounding cells.

2 Network operation and modeling

2.1 Network structure

The cellular network consists of N cells and each of the cells includes a base station in the center position (fig.1).

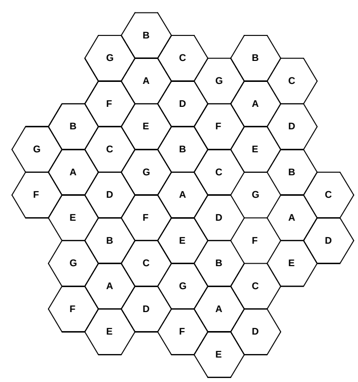

Fig 1. The network structure

Each cell is divided in a mesh of spots where the users may exist from the beginning of the call or due to hand-of situation.

2.2 Network operation

In a real wireless network some basic procedures (events) such as *New call arrival*, *Call termination*, *Reallocation check* and *User movement* take place for different users.

The needed information for the simulation of the cellular network can be categorized as follows:

- *User characteristics* - user attributes including connection status, current position, call holding time, allocated channel, communication signal strength and interference (if necessary), etc.

- *Network parameters* - Cells number, channels per cell, cell positions, base station positions, etc.
- *Traffic and QoS* - new call arrival schemes, user movement distribution, call dropping conditions, hand-of conditions, etc.
- *Channel allocation schemes* – channel allocation strategy according to network conditions, congestions cases, resources limitations, etc.

2.3 Network procedure modeling

In order to model the user behavior and network operation we have to take in consideration some basic aspects of a GSM cellular network such as CNR on cell edge (dB), CNIR threshold (dB), average call holding time (sec), channels per cell, path loss factor(alpha), standard deviation of shadowing (sigma), cellmesh fineness, max users per cell, No. of cells, New call arrival rate, User movement rate, where the CNR represents the Carrier to Noise Ratio and the CNIR represents the Carrier to Noise plus interference Ratio.

2.3.1 New call arrival

Any new call has to fulfill certain criteria such as:

- Channel availability
- Carrier strength (between user and base station)
- Carrier to Noise ratio CNR (signal purity)
- Signal to Noise plus interference ratio CNIR (interference from other connected users)

In the simulation program, the new calls are resulted from a random or a poisson distribution with regard to with a predefined daily model. When a new call arrival occurs with regard to Poisson distribution, the program gets a random number x from Poisson distribution and calculates the corresponding P(x) which is :

$$P(x) = \frac{e^{-\lambda} \cdot \lambda^{x}}{x!} \qquad (1)$$

Where λ represents the new call arrival rate. This rate is analogous to the time of the day. A fixed set of simulation time steps represents a whole day. Each day is divided in to five zones according to traffic conditions.

After a new call arrival, several actions take place in turn:
a) Search for unconnected users in each cell
b) Calculate a random user position in the mesh
c) Place the new user according to cell's base station position and mesh spot
d) Calculate the signal strength between base station and new user in the call initiated cell.
Firstly we obtain the shadow attenuation

$$sh = 10^{\frac{\sigma \cdot n}{10}} \qquad (2)$$

where **σ** is the standard deviation of shadowing and **n** is a number from the normal distribution. Using the shadow attenuation and distance between user and base station, we can derive the distance attenuation **dw**. Finally, we calculate the CNIR (Carrier to Noise Interference Ratio) between user and base station

$$cn = 10^{\frac{cnedge}{10}} \cdot dw \qquad (3)$$

where cnedge is the CNR on cell edge (dB).
e) Scan the other cells and calculate interference among new user and other users that use the same channel
f) Check if C/(N+I) ratio is acceptable according to predefined threshold
g) If C/(N+I) is acceptable, establish the new call and update the table of user attributes, otherwise use any alternative and selected DCA variation.

2.3.2 Call termination

The program uses an exponential function that generates the call duration for each new user. The call holding time is added to current simulation time for later examination. If the user's connection time is expired the user attribute table is updated with the new connection status of the particular user.

2.3.3 Reallocation check

The computations are based on signal strength and how is affected from other connected users in neighbor cells. If a user signal does not fulfill the C/(N+I) threshold (Carrier to Noise and Interference ratio) the procedure tries to find another appropriate channel. The Carrier to Noise and Interference ratio can be derived using the type

$$R_{cni} = \frac{A P_0 d_0^{-\alpha} 10^{\frac{\xi_0}{10}}}{N + \sum_{i-1}^{n} A P_i d_i^{-\alpha} 10^{\frac{\xi_i}{10}}} \qquad (4)$$

Where **n** is the number of base stations and users, $\mathbf{d_i}$ is the distance between user and base station, $\boldsymbol{\xi_i}$ is the distortion due to shadowing from user to base station, **A** is a proportional coefficient and **P** is the transmitted power. Firstly, the algorithm calculates the signal strength between user and base station and in later time calculates any interference from around connected users. If an accepted channel is found, is allocated to the new user, otherwise the call is dropped.

2.3.4 User movement

The simulation program supports two types of user movement. The first type of user movement is based on random number generation like new call arrival and the second on Gaussian distribution. The algorithm locates the connected users and changes their current positions. The reallocation procedure in distributed DCA checks the new user positions and performs new channel assignment if needed. In centralized DCA, after user movement, the user is disconnected and the algorithm searches for a proper free channel from the central channel pool. The second type of user movement is based on the Gaussian distribution. The Gaussian distribution density function is

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \qquad (5)$$

where **σ** is the standard deviation and **μ** is the mean value. The Gaussian distribution in our program has mean value zero and standard deviation one. Hence, the density function becomes

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \qquad (6)$$

In the user movement procedure, firstly we generate a Gaussian number e.g. x_1 and the corresponding $f(x_1)$ when $x_1 \in [-0.5, 0.5]$. If another Gaussian number e,g x_2, where $|x_2| \geq f(x_1)$ a user move is generated.

3 Proposed DCA variations

Firstly, the program tries to assign a channel within the initiated cell of the new call and afterwards activates any of the following methods.

3.1 Balanced variation

The DCA unbalanced algorithm assigns the first channel that fulfills the conditions and the DCA balanced uses the least congestion algorithm for the completion of channel assignment. As we mentioned before, the balanced method uses the least congested algorithm. Initially, we assume that the least congested cell is the cell where the new call is occurred. The algorithm scans all the cells in the neighbor region and finds the least congested cell.

3.2 Best CNR variation

The best CNR method goes around the six neighbor cells of the initiated cell and calculates the CNR between user and neighbor cell base stations. After the strongest CNR is found, the program tries to assign a new channel from the corresponding cell. The algorithm initially assumes that the strongest CNR exists from the first neighbor cell and continues to calculate and compare CNR from the rest neighbor cells until the strongest CNR is found (fig.2).

```
Max CNR cell = First Neighbor cell
Current cell = First Neighbor cell
Max CNR = CNR of Current cell
LOOP
   Get first/next Neighbor cell
   Current cell = Neighbor cell
   Compute CNR for Current cell
   Current CNR > Max CNR ?
     YES :
         Max CNR cell = Current Neighbor cell
         Max CNR = CNR of Current Neighbor cell
     NO :
   Are all Neighbor cells scanned ?
     NO : Return to Loop
     YES : Terminate Loop
END LOOP
```

Fig. 2 – Best CNR algorithm

3.3 Round Blocking variation

The round blocking algorithm searches in neighbor cells and when a successful channel assignment is made the algorithm stops. If the call establishment is not successful in the last neighbor cell, the call is blocked(fig 3).

```
LOOP
   Get first/next Neighbor cell
   Compute CNR from Current BS
   Find available channel
   Compute Interference from other users
   CNIR > CNIR Threshold ?
     YES : Succeed =1
     NO : Succeed = 0
   Last Neighbor reached OR Successful Connection ?
     YES : Terminate Loop
     NO : Return to Loop
END LOOP
```

Fig.3 Round Blocking Algorithm

4 Basic Statistical metrics

Blocking probability constitutes a measure for GoS[17] (Grade of Service) level or Quality of Service[18]. This measure is one of the most important characteristics for the performance of a cellular network. When a new call arrival occurs and the network can not allocate a channel then we say that this call is blocked. The blocking probability P_{bl} is calculated from the ratio

$$P_{blocking} = \frac{number\ of\ blocked\ calls}{number\ of\ calls} \qquad (7)$$

If the received power of each user is high enough, we can make the assumption that the interference from other users can be ignored. Thus, we can compare the simulated blocking probability with the theoretical which is

$$P_{blthe} = \frac{\binom{n-1}{s}(vh)^s}{\sum_{i=0}^{s}\binom{n-1}{i}(vh)^i} \qquad (8)$$

where **n** is the number of users, **s** is the number of channels, **v** is the average call arrival rate (for no connected user) and **h** is the average call holding time. The *dropping probability* is also an additional and very important characteristic of the cellular network. When a call is in progress and the required quality conditions are not met then this call is obligatory driven to termination. The dropping probability $\mathbf{P_{fc}}$ is calculated from the ratio

$$P_{fc} = \frac{number\ of\ \ forced\ calls}{number\ of\ calls - number\ of\ blocked\ calls} \qquad (9)$$

5 Simulation results

The program produces the simulation results in *.m files (including matlab commands) for later process in matlab. The simulation results include data for calculating important measures such as blocking probability, dropping probability, channel reuse, cell congestion, number of reallocations, channel reuse per cell, number of new calls in simulation time, etc.

5.1 DCA comparative results.

We have simulated a cellular network of 19 cells capacity with 10, 50, 80,100,200,400,750 users per cell and 32 channels per cell.

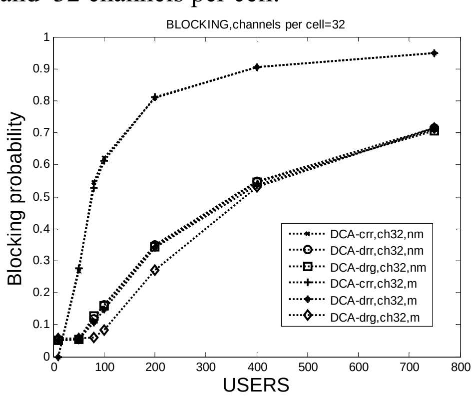

Fig.4. Blocking probability of various channel assignment schemes (32 channels per cell-random call arrival)

nm/m=no user movement/user movement,
crr=centralized DCA, random call arrival, random user movement
drr=distributed, DCA, random call arrival, random user movement
drg= distributed DCA, random call arrival, Gaussian user movement

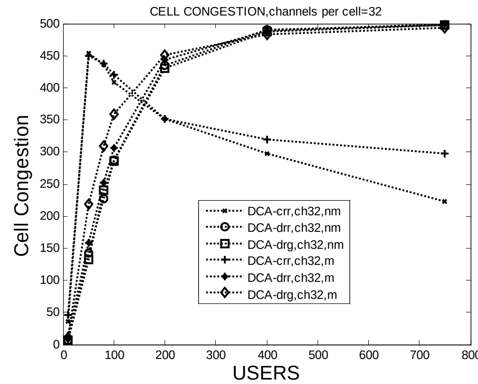

Fig. 5 - cell congestions (random call arrival)

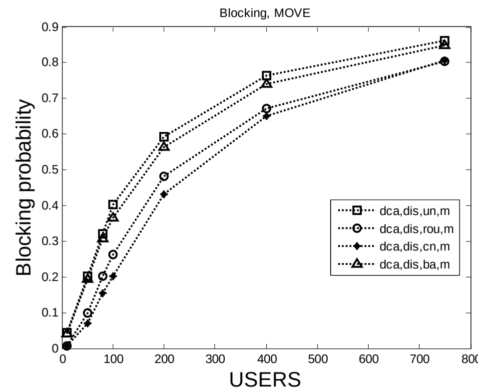

Fig. 6. Blocking Pr. of the proposed DCA variations

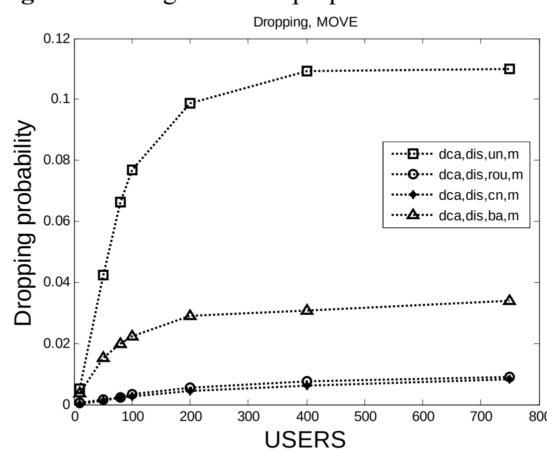

Fig. 7 – dropping Pr. of the proposed methods

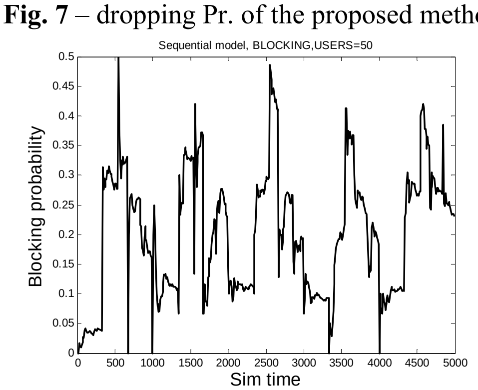

Fig. 8 Blocking Probability over simulation time

6 Conclusions & Future work

Several new efficient variations of DCA channel assignment schemes for GSM cellular systems have been presented in this paper. In order to be thoroughly evaluated a novel generic Java simulation system has been developed and thoroughly analyzed, suitable for large scale cellular systems. The divergence between simulation results and real network behavior is often affected by the structure of the implemented algorithms and the corresponding research of real network conditions like new call arrival schemes, user movement, etc. A deeper research requires full customizable software with high level of adaptation in real network specifications and behavior. The herein proposed generic simulation environment for GSM cellular networks takes into account the most important such factors and models them in such a detail so as to extract clear and reliable conclusions for random and not ad hoc cellular systems as it is usually the case.

Another interesting point for further investigation is the algorithmic and computational complexity as well as possible optimization methods in channel assignment schemes. In order to develop an efficient and useful simulation environment we have to study the evolution, the specifications and the constrains of real cellular networks as well as the most appropriate modeling schemes that could be involved for such real systems simulations regarding user and network model, like multi-threading.

References

[1] Oscar Nierstrasz. A survey of object-oriented concepts. In W. Kim and F. Lochovsk, editors, Object-Oriented Concepts, Databases and Applications, pages 3--21. ACM Press and Addison Wesley, (1989).

[2] R.L.Banrodia, Et al, Parsec: A parallel simulation environment for complex systems, IEEE Computer, 21(10): (1998)77-85, Oct.

[3] Karian, Z. A.,Dudewicz, E. J.: Modern Statistical, Systems, and GPSS Simulation - The First Course; New York (1991).

4] Russell, E. C.: Building Simulation Models with SIMSCRIPT II.5; C.A.C.I., Inc., Los Angeles (1983).

[5] Joel West and Alasdar Mullarney. ModSim: A language for distributed simulation. Proceedings SCS Multiconference on Distributed Simulation, pages 155-159, San Diego, California, February (1988).

[6] J. Miller, O. Weyrich and D. Suen, A Software Engineering Oriented Comparison of Simulation Languages, Proceedings of the 1988 Eastern Simulation Conferences: Tools for the Simulationists, Orlando,1988.

[7] M.Zhang, and T. S. Yum, “Comparisons of Channel Assignment Strategies in Cellular Mobile Telephone Systems”, IEEE Transactions on Vehicular Technology, vol.38,no.4,pp211-215,1989.

[8] W.K. Lai and G.C. Coghill, “Channel Assignment through Evolutionary Optimization”, IEEE Transactions on Vehicular Technology, vol.45,no.1,pp91-96,1996.

[9] V.H. MacDonald, “The cellular Concepts,” The Bell System Technical, Journal, vol.58, pp.15–42, 1979.

[10] S. M. Elnoubi, R. Singh, and S.C. Gupta, “A New Frequency Chan-nel Assignment Algorithm in High Capacity Mobile Communication Sys-tems”, IEEE Transactions on Vehicular Technology, vol. VT-21, no. 3,pp. 125–131, 1982.

[11] Z. Xu and P.B. Mirchandani, “Virtually Fixed Channel Assignment for Cellular Radio-Telephone Systems: A Model and Evaluation”, IEEE International Conference on Communications, ICC’92, Chicago, vol. 2, pp. 1037–1041, 1982.

[12] L.J. Cimini and G.J. Foschini, “Distributed Algorithms for Dynamic Channel Allocation in Microcellular Systems”, IEEE Vehicular Technology Conference, pp.641-644, 1992.

[13] D. C. Cox and D. O. Reudink, “Increasing Channel Occupancy in Large Scale Mobile Radio Systems: Dynamic Channel Reassignment”, IEEE Transanctions on Vehicular Technology, vol.VT-22, pp.218–222, 1973.

[14] E. Del Re, R. Fantacci, and G. Giambene, “A Dynamic Channel Alloca-tion Technique based on Hopfield Neural Networks”, IEEE Transanctions on Vehicular Technology, vol.45, no.1, pp.26–32, 1996.

[15] K.N. Sivarajan, R.J. McEliece, and J.W. Ketchum,“Dynamic Channel Assignment in Cellular Radio”, IEEE 40th Vehicular Technology Confer-ence, pp.631–637, 1990.

[16] T.J. Kahwa and N.D. Georgans, “A Hybrid Channel Assignment Schemes in Large-Scale, Cellular Structured Mobile Communication Sys-tems”, IEEE Transactions on Communications, vol.26, pp 432–438, 1978.

[17] T.S. Rapaport, “Wireless Communications Principles and Practice”, Prentice Hall, 2002

[18] M.Salamah and H.Lababidi, “Dynamically adaptive channel reservation scheme for cellular networks”, Elsevier Computer networks, article in press, 2005