Coverage and Rate Probability in Hexagonal Cell Structure

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Abstract

Fractional Frequency Reuse (FFR) is an interference coordination well suited to OFDMA based wireless network where in cells is divided into special region with various frequency reuse factors. The research focuses at understanding the concept as well working of FFR in Hexagonal geometrical structure for analytical frame work and comparison. The project plan includes the extensive literature review of both concepts as well as previous research works. The study leads to the need of a simulator for examining and analyzing FFR in orthogonal and synchronous cellular systems. In comparison with the traditional grid model for FFR in cellular system, the hexagonal geometry is much reliable with omni base stations. For this, designing a simulator for the same proves to be very useful in the industry.

1. Introduction

1.1 Cellular System

A cellular System is a radio network distributed over land areas called cells, each served by at least one fixed-location known as a base station. In a cellular network, each cell uses a different set of frequencies from neighbouring cells, to avoid interference and provide guaranteed bandwidth within each cell.

When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission.

In a cellular radio system, a land area to be supplied with radio service is divided into regular shaped cells, which can be hexagonal, square, circular or some other regular shapes, although hexagonal cells are conventional. Each of these cells is assigned multiple frequencies (f_1 - f_6) which have corresponding radio base stations. The group of frequencies can be reused in other cells, provided that the same frequencies are not reused in adjacent neighbouring cells as that would cause co-channel interference.

The increased capacity in a cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission. If there is a single plain transmitter, only one transmission can be used on any given frequency. Unfortunately, there is inevitably some level of interference from the signal from the other cells which use the same frequency. This means that, in a standard FDMA system, there must be at least a one cell gap between cells which reuse the same frequency.

1.2 Frequency Reuse

The growing demands on mobile networks to support data applications at higher throughputs and spectral efficiencies has driven the need to develop Orthogonal Frequency Division Multiplexing (OFDM) based 4th generation (4G) networks, including WiMAX and 3GPP Long Term Evolution (LTE). A key objective with respect to deployment of OFDM 4G networks is to utilize a frequency re-use.

The key characteristic of a cellular network is the ability to re-use frequencies to increase both coverage and capacity. The frequency reuse factor is the rate at which the same frequency can be used in the network.

There is growing need for analysis of 4G systems with aggressive frequency reuse. Creating a simulator for such systems should be achieved. Another goal is to be able to extract some meaningful information from its results.

In a cellular system, neighboring cells will use different portions of the available frequency band in order to reduce ‘Other-Cell-Interference’ (OCI). Cells which are quite distant from one-another will then operate on the same frequency – such a pair would be called co-channel cells. Although the implementation of frequency use is a guaranteed way to decrease interference and thus increase a mobile's Signal to Interference-plus- Noise Ratio (SINR), it is not without its drawbacks. Dividing the available spectrum limits the bandwidth available to each mobile, therefore limiting the capacity of the channel [11].

There are two common used frequency allocation schemes. One is to reuse the total bandwidth in each sector. This frequency reuse factor is 1. It is illustrated in Fig 1.

The other scheme is that the total bandwidth is reused every three sectors, and each sector uses disjoint frequency band. It is illustrated in Fig 2, where the transmit power is increased (in Figure 2, λ ≧1) as the total transmit power is now allocated into 1/3 of the total bandwidth.

Interference from adjacent sectors is eliminated and hence the user throughput and the packet error rate are largely improved. However, as each sector uses only 1/3 of the bandwidth, the spectral efficiency is less than that of the scheme with frequency reuse factor of 1.

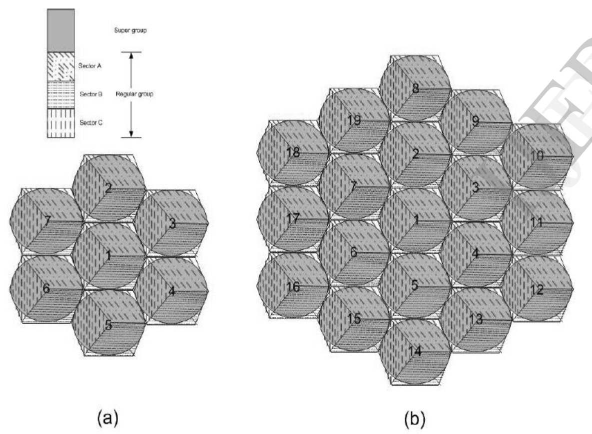

Fig 1 Fractional Frequency Reused based cell models (a) 7-cell grid (b) 19-cell grid. [10]

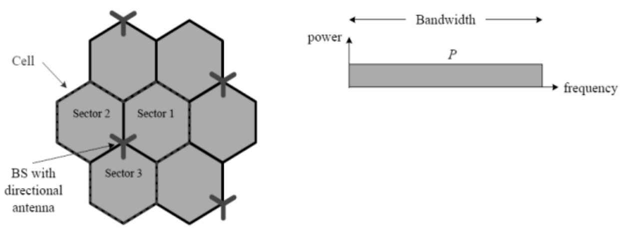

Fig 2 Frequency allocation with reuse factor of 1 [5]

C. Fractional Frequency Reuse

In order to improve the cell-edge user throughput and at the same time retain the spectral efficiency, the scheme of fractional reuse, which means that there are various frequency reuse factor in the frequency allocation in one sector, the total bandwidth is considered. By considering the advantages of frequency reuse 1 and 3, we divide the total bandwidth into two parts, one is sector center band and the other is sector edge band. The sector center band applies frequency reuse 1 to keep spectral efficiency. While the sector edge band applies frequency reuse 3 to enhance edge users' throughput. See Fig 3 for reference. The sector edge band is further divided into three frequency groups, which are specified by green, blue and red colors, respectively. Each group is non-overlapped to avoid interference. It is similar to the scheme of frequency reuse 3 (Fig 2).

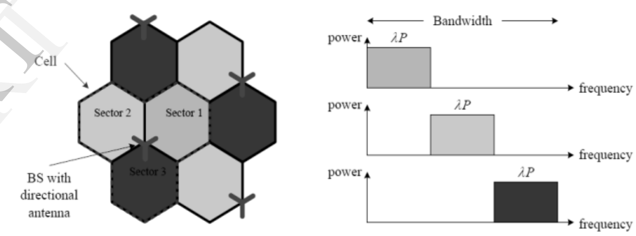

Fig 3 Frequency planning with reuse factor of 3 (with λ ≧1) [5]

The interference-limited users (i.e., the user at the cell/sector edge) are scheduled using this band in their sector. Under the constraint of total transmit power, the power transmitted to the edge users can be increased (in Fig 3, $\alpha 1$ ≧1). The increased power level can further enhance the signal quality and hence the throughput of the users at the cell-edge. Comparing with frequency reuse 1 (Fig 1) and frequency reuse 3 (Fig 2), the spectral efficiency of this scheme (Fig 3) is less than that of Fig 2 because some frequency band is reserved without transmission to avoid interference. However, the throughput of sector edge users is large increased.

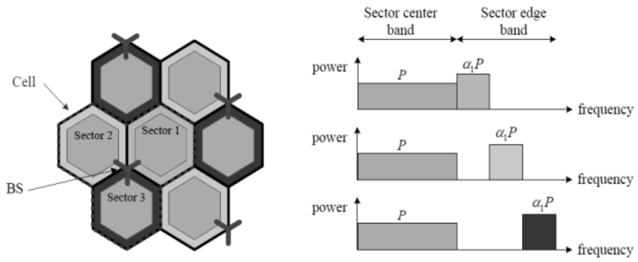

Fig 4 Frequency allocation for fractional frequency reuse (with α1 ≧1) [5]

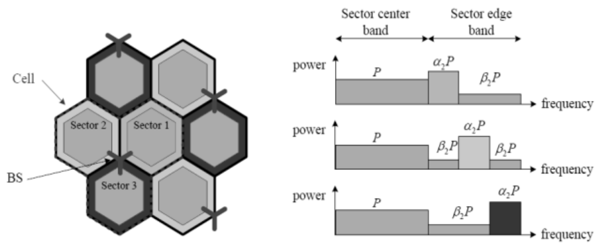

Fig 5 Frequency allocations for soft fractional frequency reuse [5]

2. Problem Identifiaction

2.1 Approaches and Their Limitations

There are a few simplistic models that prove successful for asynchronous non-orthogonal implementations such as 3G CDMA however none hold well for orthogonal structures like WiMax or LTE. CDMA as being a spread-spectrum technique, there is no need for frequency re-use between cells (the effect can be achieved by ensuring that no pseudo-noise code is duplicated between neighboring cells). The lack of orthogonality and synchronicity give no specific pattern to interfering signals, thus all interference is easily regarded as noise. For these reason modeling effects of CDMA are considerable simpler in terms of bandwidth considerations. This puts a large importance on accurately measuring such interference as doing so can help achieve high spectral efficiency in the following years as 4G systems take off [6].

A tractable but overly simple downlink model commonly used by information theorists is the Wyner model [7], which is typically one-dimensional and presumes a unit gain from each base station to the tagged user and an equal gain that is less than one to the two users in the two neighboring cells. This is a highly inaccurate model unless there is a very large amount of interference averaging over space, such as in the uplink of heavily-loaded CDMA systems [8]. This philosophical approach of distilling other-cell interference to a fixed value has also been advocated for CDMA in [9] where other-cell interference was modeled as a constant factor of the total interference. For cellular systems using orthogonal multiple access techniques such as in LTE and WiMAX, the Wyner model and related mean-value approaches are particularly inaccurate, since the SINR values over a cell vary dramatically. Nevertheless, it has been commonly used even up to the present to evaluate the "capacity" of multicell systems under various types of multicell cooperation. Another common analysis approach is to consider a single interfering cell. In the two cell case, at least the SINR varies depending on the user position and possibly fading, but naturally such an approach still neglects most sources of interference in the network and is highly idealized. A recent discussion of such models for the purposes of base station cooperation to reduce interference is given in. That such simplified approaches to othercell interference modeling are still considered state-of-the-art for analysis speaks to the difficulty in finding more realistic tractable approaches.

3. Methodology

3.1 Model

The model built by the simulator will be created by first distributing the base-stations across the plane. This will be done using simple hexagon geometry. The cells will be given an integer "label" indicating which frequencies are to be used in a frequency reuse scheme; this is not done randomly but systematically such that the pattern of labels is uniform across the map.

Next a number of mobiles (determined by the user) will be randomly scattered across the cells. At this point, for each mobile it will be determined which base-station will be communicating with it (the closest), the corresponding distance between them as well as the frequency band they will be transmitting on. At this point the SINR and Rates achieved by each mobile will be computed using the formulae laid out in it [1]. It is worth noting that with frequency reuse, since each mobile's relevant bandwidth is cut by the reuse factor, the amount of spectral noise is also limited accordingly.

The code itself is implemented in MATLAB. It is made up of 2 function files and an interactive Graphical User Interface (GUI) to manipulate them. The job of the GUI is to simply take in parameters relating to the specifics of the desired simulation.

The model can run a types of simulation termed as Specific Reuse Pattern. Specific Reuse Pattern that finds the probability that user gets coverage (meets certain Rate and SINR values) over several threshold values.

The majority of the exact computations involved in the simulations follow directly from the earlier discussion of [1]. The only large difference arises in dealing with fractional frequency reuse. The first step in dealing with fractional reuse is to assume that all mobiles are not in the center fraction, thus using the resources (power and bandwidth) allocated to the normal reuse users (determined in GUI). Then each mobile will be tested to see if it passes a certain criterion (determined in GUI), if it does, it will be reassigned to the center fraction of its cell. Then SINR will be recalculated using updates resources and interference patterns. When the rate will be calculated it is not as simple as dividing by the frequency reuse factor as stated in the literature. In this case it must be determined if the mobile is in the center fraction (not dividing by δ) or the normal outer-reuse portion (divide this portion by δ) which still proves to be a simple check and calculation.

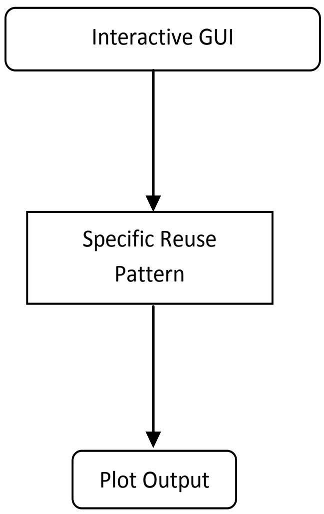

Fig 6 Flow Chart of the Proposed GUI Simulator

4. Result

4.1 Frequency Reuse

Regardless of the simulation type, the model plots a map of the frequency reuse. Figure 7 illustrates a reuse deployment with number of rings = 9. Each colored circle represents a base-station of a certain assignment. The small black dots represent mobiles. Note that the mobiles are only placed on the inner part of the map – this avoids downlink boundary effects, that is to say each mobile is allowed a large amount of interfering stations.

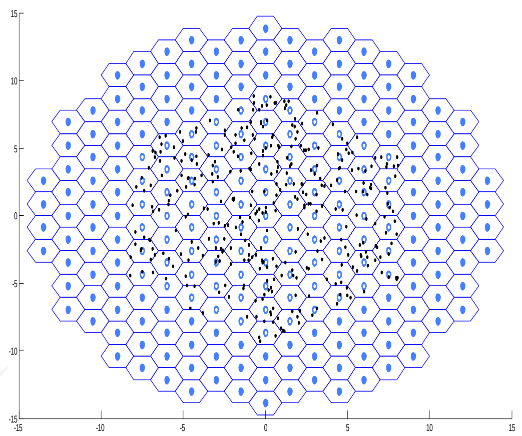

Fig 7 Frequency Reuse (No. of rings = 9)

4.2 Coverage probability

The model provides the coverage probability plot with respect to SINR. Figure 8 illustrates the coverage probability at frequency reuse factor = 1. The plotting is been done with five different values at mean, minimum, maximum, one standard deviation above mean and one standard deviation below mean.

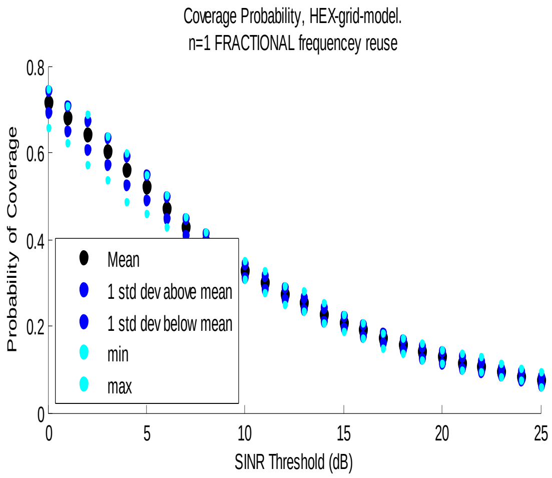

Fig 8 Coverage Probability (Reuse Factor = 1)

4.3 Rate probability

The model also provides the rate probability plot with respect to SINR. Figure 9 illustrates the rate probability at frequency reuse factor = 1. The plotting is been done with five different values at mean, minimum, maximum, one standard deviation above mean and one standard deviation below mean.

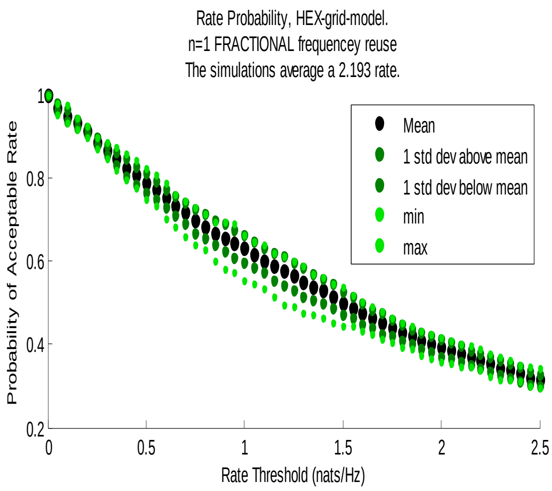

Fig 9 Rate Probability (Reuse Factor = 1)

5. Conclusion

Due to increased traffic demands in interference-limited cellular networks, fractional frequency reuse (FFR) is an attractive strategy because to its low complexity implementation and significant gains for the bottom percentile of mobile users.

Various studies aim at developing new general models for the multi-cell signal-to-interference-plus-noise ratio (SINR) using stochastic geometry. Under very general assumptions, the resulting expressions for the downlink SINR CCDF (equivalent to the coverage probability) involve quickly computable integrals, and in some practical special cases can be simplified to common integrals (e.g., the Q-function) or even to simple closed-form expressions.

The complete literature survey has been completed along with the study of results determined in the reference papers. On the basis of the study, it has been concluded that the key aspects has been understood and followed accordingly to the requirement for the simulator to be designed. Instead of relying on system simulation based on deterministic access point location, this simulator will aim at an analytical model for evaluating fractional frequency reuse in hexagonal geometrical structure.

In view of current trends, as this research work goes on, the performance analysis of various cellular systems will be considered for comparison. This comparison will lead to the further real life analytical framework for the said purpose.

6. Future Work

Work At some point it would be great to implement an option for the user to choose hexagonal base-station deployment or the Poisson deployment proposed by [1]. At first glance this problem seems very difficult to implement with a fractional reuse scheme, however as mentioned in section 6 of their paper, there are no glaring differences between using a greedy algorithm to assign reuse “labels” (the method closest to creating the typical pattern we are used to in a hex or grid model) and using random assignments. This makes the task much easier from a simulation implementation point of view. With the integer-reuse accounted for the fractional portion follows naturally by using a simple SINR/Rate threshold as currently is done. Also as mentioned in the concluding words of [3], it would be helpful to include functionality with heterogeneous networks. This is a significantly more involved analysis than what is currently implemented, but given the current technique, taking the code from its current state to heterogeneous may involve a few iterations similar to taking the code from integer reuse to fractional reuse. It would be quite involved yet feasible.

7. REFERENCES

[1] J. G. Andrews, F. Baccelli, and R. K. Ganti, "A tractable approach to coverage and rate in cellular networks," IEEE Transactions On Communications, Vol. 59, No. 11, November 2011

[2] T. D. Novlan, R. Krishna Ganti, A. Ghosh, and J. G. Andrews, "Analytical Evaluation of Fractional Frequency Reuse for OFDMA Cellular Networks", IEEE Transactions On Wireless Communications, Vol. 10, No. 12, December 2011

[3] T. D. Novlan, R. Krishna Ganti, A. Ghosh, and J. G. Andrews," Analytical Evaluation of Fractional Frequency Reuse for Heterogeneous Cellular Networks", IEEE Transactions On Communications, Vol. 60, No. 7, July 2012

[4] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4G networks," IEEE Communications Magazine, vol. 47, Apr. 2009.

[5] C. L. Tsai, R. Chen, C. L. Ho, Y. X. Zheng, R. L. ITRI and W. H. Sheen, "Interference Mitigation for 802.16m", IEEE 802.16 Broadband Wireless Access Working Group, Jul.2008.

[6] J. Xu, J. Zhang, and J. G. Andrews, "When does the Wyner model accurately describe an uplink cellular network?" in *Proc. IEEE Globecom*, Dec. 2010.

[7] K. S. Gilhousen, I. Jacobs, R. Padovani, A. J. Viterbi, L. Weaver, and C. Wheatley, "On the capacity of a cellular CDMA system," *IEEE Trans. Veh. Technol.*, vol. 40, no. 2, pp. 303–12, May 1991.

[8] C. B. Chae, I. Hwang, R. W. Heath, and V. Tarokh, "Interference aware-coordinated beamform system in a two-cell environment," to be published.

[9] D. Gesbert, S. Hanly, H. Huang, S. Shamai, O. Simeone, and W. Yu, "Multi-cell MIMO cooperative networks: a new look at interference," *IEEE J. Sel. Areas Commun.*, vol. 28, no. 9, pp. 1380–1408, Dec. 2010.

[10] Syed Hussain Ali and Victor C. M. Leung, "Dynamic Frequency Allocation inFractional Frequency Reused OFDMA Networks", Transactions On Wireless Communications, VOL. 8, NO. 8, August 2009.

[11] T. S. Rappaport, "Wireless Communications: Principles and Practice", 2nd Edition, Prentice Hall PTR, 2002.