Downlink Throughput Statistics in interference-limited cellular systems based on Monte-Carlo Simulation Method

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Abstract: This paper considers the application of Monte-Carlo Simulation Method to quantify mean throughputs in interference-limited cellular systems along antenna pattern and frequency re-use factor. Firstly, we calculate the path loss between center cell to victim link receiver and all co-channel cells to victim link receiver to determine desired and undesired signals respectively. Next, AWGN and Shannon's capacity have been used as a comparison to analyze the performance of throughputs in interference-limited cellular systems. The simulation results show that a re-use factor of N=1, directional antenna has improvement in the Shannon capacity by 242.2 % over Omni-directional antennas whereas a frequency re-use factor of N=7 has increased to Shannon capacity by114% for N=7 over N=1.

Index Terms: Monte Carlo, AWGN, Omni Direction, MIMO

1. Introduction

Usable radio frequencies are a very limited resource in nature. There are only 25MHz and 75MHz bandwidths available in GSM 900 and 1800MHz respectively [1], [2]. Therefore, increasing demand of the existing radio applications and the introduction of the new applications have created a big challenge in radio spectrum resources management [1], [3], [4]. The cellular concept was a a great solution in adressing the problem of spectral congestion in wireless communication [1], [4], [5]. This system has offered very high capacity in a very limited spectrum wireless communication by spacing these limited spectrum over some predefined distance over again [1], [4], [5]. However, re-using the same radio frequencies over again introduce radio frequency interference.

Co-channel interference (CCI) is dominant radio frequency interference that comes from other cells reusing the same frequencies channel [1], [2], [4]–[12]. Thus, it is a limiting factor in a cellular system. To mitigate bottleneck effect of CCI, larger re-use factors [1], [4], [13], sectored Base Station antennas [1], [4], [13], microcells and cell-splitting [1], [5], multi-user diversity[14], [15], and Base Station co-ordination[10] have been proposed.

However, to quantify the spectral performance of these mitigation techniques, mostly analyical methodologies have been proposed in the literature. Authors in [6] computed mean throughputs for a wide range of MIMO system design parameters using realistic analaytical models for co-channel interference. Authors in [7] investigated spectral efficiency capabilities of a cellular data system that combines the multiple transmit signals, adaptive array processing at the receiver, and aggressive frequency re-use. They quantified spectral efficiency, using analytical simulations, to characterize MIMO systems performance for a wide variety of channel conditions. Authors in [12] used analytical method to quantify mean throughputs in interference-limited singleinput-single-output and multi-element antenna cellular systems.

Signal to interference plus- noise ratio had been used in [6], [7], [12] to quantify the attainable system-level throughputs of interference-limited using an analytical approaches.

In this Study, we have used a CCI since thermal noise has a very minimal effect in throughput analysis [1], [13]. To determine the cellular system throughput performance over a wide coverage area, cell wide CCI due to the randomness of users' location is collected from the first tier of co-channel cells using a Monte-Carlo Simulation method for total of 5,000 events. Monte-Carlo Simulation method has been picked over analytical method on the grounds that, the authors in [3], [16]–[19] presumed that the Monte-Carlo method is a superior to examine complex interference than the analytical method.

2. Method

The cellular systems are designed in a hexagonal shape [1], [2], [4], [5], [13], [14], [18], [20]. The Victim Link Receiver (VLR) is assumed to be the middle of the layout and being served by the Victim Link Transmitter (VLT). In the fully hexagon-shaped cellular system, there are 6 interfering transmitters in the first tier and 12 transmitters in the second tier and so on [1], [13]. When the total interference from Co-

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channel cells to VLR is evaluated, the most severe interference comes from the first tier. CCI can be calculated from the parameters of interfering link transmitters and victim link receivers. Victim link consists of victim link transmitter, radio path, and victim link receiver as shown in Table 1 [3], [16], [17]. Interfering links consists of one or more interfering transmitters, radio path and wanted receiver as shown in Table 2 [3], [16], [17]. The radio path (Link budget) depends on transmitter power, antenna gain, operating frequency and distance between transmitter and receiver.

Table1: Parameters of interfering transmitter [3], [16], [17]

Parameters	*values*
Power	33dBm
Emission mask	-36 dBm per 100 kHz for GSM 900MHz [21]
Frequency	Absolute Radio Frequency Channel Number 10 (937MHz)
Bandwidth	200kHz
Antenna height	33m
Gain	14.5dbi
Distance	Distance to victim receiver depends on the random position of victim
Propagation model	Free space
Cell size	3km

The re-use distance (D) is defined to be the distance between the two co-channel cells using the same frequency [1], [4], [5], [13], [14]. The re-use distance can be calculated from Equation (1) as given in [1] [2], [4], [13].

$$D = \sqrt{(i^2 + ij + j^2)}(R\sqrt{3}) \quad (1)$$

Where i and j are non-negative integers, D is the re-use distance, and R is the coverage area of the cell in the middle of the hexagons.

To find the nearest co-channel neighbors of a particular cell, one must do the following: (1) move i cells along any chain of hexagons and then (2) turn 60 degrees counterclockwise and move j cells [1].

Table 2: Parameters of victim link

Parameters	*Values*
Power (vlt)	33dBm
Frequency (vlt)	Absolute Radio Frequency Channel Number10 (937MHz)
Bandwidth(vlt)	200kHz
Antenna height(vlt)	33m
Gain(vlt)	14.5dBi
Pattern(vlt)	Three sector
Distance(vlt)	Distance between vlt and vlr varies according to random position of vlr in the coverage area of vlt
Cell size(vlt)	2.5km
Propagation model	Free space model
Sensitivity(vlr)	-101.5 [17]
Blocking mask(vlr)	First adjacent channel=-9 dB, Second adjacent channel = -41 dB, Third adjacent channel, =-49 dB[22].
Bandwidth(vlr)	200kHz
Antenna Height(vlr),	1.5m
Noise Floor	9dB[17]
Gain(vlr)	2dB

The simulation methodology for one snapshot is summarized as follows:

i. Decide the location of the center cells and all the surrounding co-channel cells in the cluster according to the re-use distance using Equation (1)
ii. Drop victim link receivers into the coverage of the center cell in cluster randomly and uniformly
iii. Calculate the path loss between center cell to victim link receiver and all co-channel cells to victim link receiver.
iv. Calculate the wanted signal from the center cell at the victim link receiver (dRSS) and unwanted signal (iRSS) at the victim link receiver from all the co-channel. Then record carrier to interference.

2.1. Throughput Analysis

Channel throughput analysis was pioneered by Claude Shannon in the late 1940s. Shannon defined any data rate higher than capacity could not be achieved without an error probability bounded away from zero [14]. Shannon (Ergodic) Capacity

We determine the instantaneous throughput for two extreme cases as given in [6], [10], [11].

Ideal Coding: This throughput is upper- bounded by the Shannon capacity

$$C = Blog2(1+\gamma) \quad (2)$$

Where B is the bandwidth, γ is instantaneous C/I

No Coding: This throughput was accurately approximated by authors in [6], [10], [11]. Equation (3) assumes M-QAM modulation, where M is binary number (2, 4, 8, …) chosen adaptively to maximize throughput for given C/I.

$$C = Blog2(1+\gamma/6.4) \quad (3)$$

Where B is the bandwidth, γ is instantaneous C/I

In the event that capacity ought to be evaluated over a fading channel, γ becomes a random variable. So the ergodic capacity is the average of C over the pdf of γ. Shannon capacity of a fading channel with receiver channel side information (CSI) for an average power constraint can be obtained from results in [14] as follow in Equation (4).

$$C = \int_0^\infty Blog2(1+\gamma)\, p(\gamma) d\gamma$$

Where B is the bandwidth, γ is instantaneous C/I

(4)

3. Numerical Results

Increasing the re-use factor from N= 1 to N= 7 moves the interfering link transmitters farther away [1], [2], [4], [7], [11]–[14], [17] , and hence, significantly improves system performance and Shannon capacity as shown in Figure 1 and Figure 2. However, total bandwidth per a single site reduces, since in N=7 each site has 1/7 the number of available channels compared to N=1.

As shown in Figure 1, an AWGN capacity with directional antenna is increased by 103.62% for the reuse factor of N=1 and by 74% for re-use factor of N=7 compared to AWGN with Omni directional antenna for re-use factor of N=1 and N=7 respectively.

Shannon capacity is increased by 42.78%% as we increase the re-use factor from N= 1 to N= 7 for omnidirectional antenna. Whereas, using directional antennas and a re-use factor of N=1 leads to about a 128.41 % improvement in Shannon capacity with ideal coding over the results for Omni-directional antennas. At a re-use factor of N=7, However, the increase due to directional antennas is 80.67%; the re-use factor N=7 has already reduced co-channel interference to a point that directional antenna can only bring about modest returns.

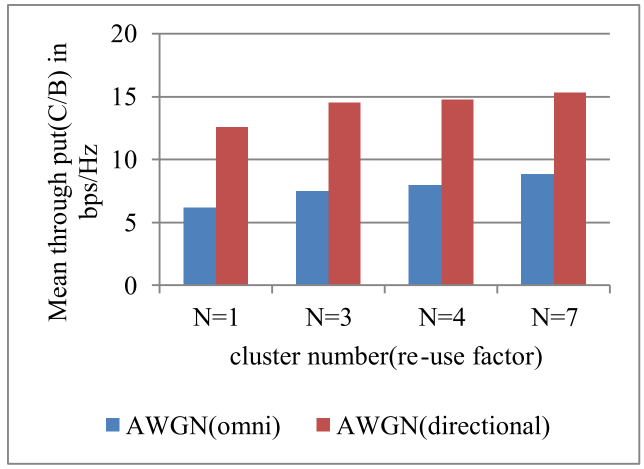

Figure 1: Throughput comparison for different re-use distances vs antenna pattern

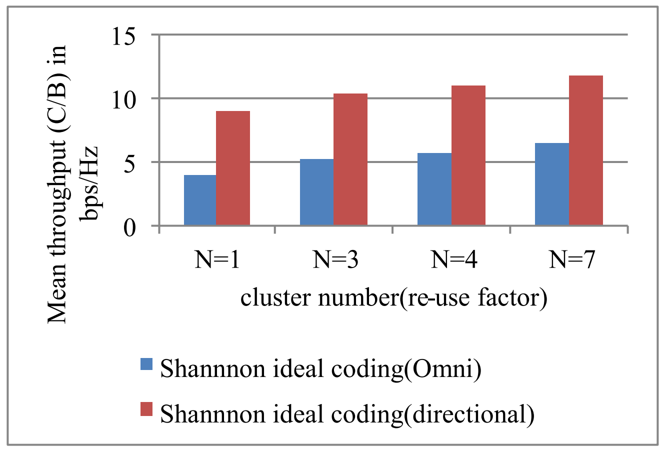

Figure 2: Effect of directional antenna on Shannon (ideal coding) capacity vs antenna pattern

Similarly for a re-use factor of N=1, directional antenna has increased 242.2 % improvement in Shannon capacity with no coding over the results of Omnidirectional with N=1 and whereas re-use factor of N=7 has 114% improvement in Shannon capacity with no coding over the results of Omni-directional with N=1.

(Fig 3)

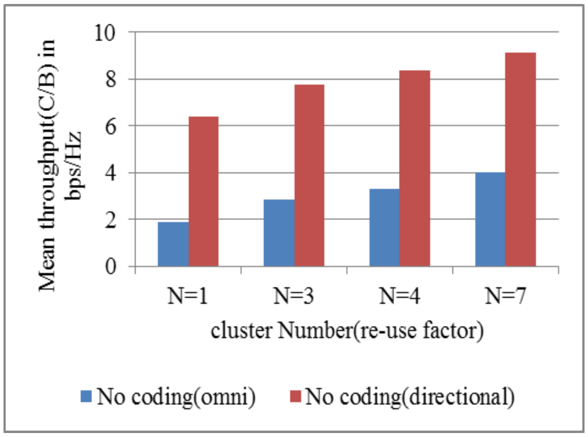

Figure 3: effect of directional antenna on Shannon (no coding) capacity vs antenna pattern

4. Summary

In this paper, the validity of the Monte-Carlo Simulation Method to model cell-wide mean throughputs in interference-limited cellular systems along larger re-use factor and antenna pattern has been tested.

5. Conclusion

The simulation results from the Monte-Carlo method have looked at two co-channels mitigation techniques. The results show sectored base station antenna has increased two fold on Shannon capacity over larger re-use factor. Along these lines, co-channels interference might be better mitigated by using beam forming techniques at transmissions or receptions.

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