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Improved spectral utilization in multi-hop relay networks using frequency reuse for 4G networks

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Abstract—This paper presents a method to improve the spectral utilization in Multi-hop Relay (MMR) networks. Co-channel interference is considered as a parameter to analyze the performance of MMR (IEEE 802.16j) based relay networks. Frequency reuse technique is a way to improve the spectral utilization. Since the same frequency band is used by Relay stations and Base Station, co-channel interference within a cell becomes a major problem. This degrades the uniform Quality of Service (QoS) within the cell. As an effective way to analyze the co-channel interference, signals are retransmitted again by the transmitting stations. From the simulation results it is observed that when the number of mobile stations is increased, signal to interference ratio (SIR) is improved.

Index Terms —multi hop, frequency reuse, interference cancellation

1 INTRODUCTION

Cellular communications has experienced explosive growth in the past two decades. Today millions of people around the world use cellular phones. Cellular phone allows a person to make or receive a call from almost anywhere. Likewise, a person is allowed to continue the phone conversation while on the move. Cellular communications is supported by an infrastructure called a cellular network, which integrates cellular phones into the public switched telephone network.
The cellular network has gone through three generations. The first generation of cellular networks is analog in nature. To accommodate more cellular phone subscribers, digital TDMA (time division multiple access) and CDMA (code division multiple access) technologies are used in the second generation (2G) to increase the network capacity. With digital technologies, digitized voice can be coded and encrypted. Therefore, the 2G cellular network is also more secure.
The third generation (3G) integrates cellular phones into the internet world by providing high speed packet-switching data transmission in addition to circuit-switching voice transmission. The 3G cellular networks have been deployed in some parts of Asia, Europe, and the United States since 2002 and will be widely deployed in the coming years.

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1.1 frequency spectrum

In cellular mobile communication, frequency spectrum is a precious resource which is divided into non-overlapping spectrum bands which are assigned to different cells (In cellular communications, a cell refers to the hexagonal/circular area around the base station antenna). However, after certain geographical distance, the frequency bands are re-used, i.e. the same spectrum bands are re-assigned to other distant cells. The frequency spectrum allocated for cellular communications is very limited. The success of today's cellular network is mainly due to the frequency reuse concept. This is why the coverage area is divided into cells, each of which is served by a BS. Each BS (or cell) is assigned a group of frequency bands or channels.

1.2 interference

The co-channel interference arises in the cellular mobile networks owing to this phenomenon of frequency reuse. Co-Channel interference is one type of interference in which besides the intended signal from within the cell, signals at the same frequencies (co-channel signals) arrive at the receiver from the undesired transmitters located (far away) in some other cells and lead to deterioration in receiver performance. So there is a need to cancel the co-channel interference. Thus, this work concentrates on cancelling the co-channel interference. IEEE 802.16 is a series of Wireless Broadband standards authored by the Institute of Electrical and Electronics Engineers (IEEE). The IEEE Standards Board is established a working group in 1999to develops standards for broadband Wireless Metropolitan Area Networks. The Workgroup is a unit of the IEEE 802 local area network and metropolitan area network standards committee. IEEE 802.16j is a new standard which defines the mobile multi-hop relay (MMR) operation between WiMAX BS and MS. The RS in IEEE 802.16j WiMAX network that aids good quality communication between BS and MS play a critical role in scheduling. In IEEE 802.16j networks, introduction of RS requires the frequency bandwidth allocation scheme which is different from the IEEE 802.16 Standard because BS and RS share the frequency bandwidth of the whole system. Therefore, many research have been conducted to efficiently allocate the frequency bandwidth efficiently to BS and RS.

The remainder of this paper is organized as follows. Section 2 describes our proposed scheme. In Section 3, we discuss the performance analysis and simulation results. Finally, we summarize the work and draw conclusions in Section IV.

2 Co-channel interference

In IEEE 802.16j networks, introduction of RS requires the frequency bandwidth allocation scheme which is different from the IEEE 802.16 Standard because BS and RS share the frequency bandwidth of the whole system. Therefore, many researches [1], [2], [3] have been conducted to efficiently allocate the frequency bandwidth efficiently to BS and RS.
K. Park and C. Kang [3] propose the extreme cases with 3-RS topology, full reuse (overlapped allocation scheme) and no reuse (orthogonal allocation scheme). The overlapped allocation allows all three RSs to use the same frequency bandwidth, which may cause the co-channel interference. MSs on the border between two neighboring sub-cells covered by the RSs using the same frequency bandwidth may experience the severe service degradation or even outage. MCS (Modulation and Coding Scheme) levels located on the border between two sub-cells (a sub cell is a small area covered by RS) edge are usually very low or even go below the outage level. Orthogonal allocation removes outage for the MSs on the border, but it suffers from the low system throughput.

2.1 frequency reuse factor

In [2], W-H Park and S. Bahk considered varying the level of reuse in a relay network with 6 RSs surrounding a BS (a 6-RS topology). The frequency reuse factors (FRF), 1, 2, 3and 6, represent the scenarios where 6, 3, 2, or 1 RS(s) share the same frequency bandwidth, respectively. FRF=1 represents the highest level (full reuse) while FRF=6 represents the lowest level (no reuse). As the level of reuse goes higher, the outage rate also goes higher, showing trade
-off between reuse level and the outage rate.

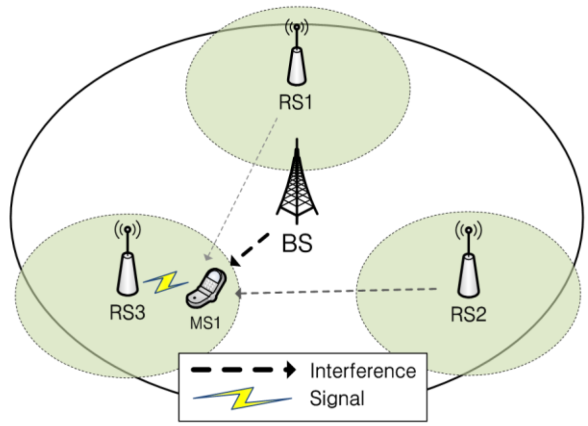

Fig.2.1. Te co-channel interference caused by frequency reuse

We also observe the system throughput among MSs for the above known schemes, and devise a novel transmission scheme to cancel the co-channel interference within a cell for the MSs on the border. In our scheme, each transmitting station transmits phase shifted signals of original signal to MS, and then MS combines the received signals and is able to recover the intended signal. Therefore, our scheme improves the system throughput among MSs compared to conventional schemes [1].

The IEEE 802.16 is a series of telecommunication standards that provides Broadband Wireless Access (BWA) services and has received great attention worldwide. The IEEE 802.16j emerged as a standard in the middle of 2009, specifying the procedure of supporting Mobile Multi-hop Relay (MMR) networks. Signal travels over the air directly from a wireless transmitter to a wireless receiver in two methods line of sight and non line of sight.

Lin Line of sight (LOS) is a condition where a signal travels over the air directly from a wireless transmitter to a wireless receiver without passing an obstruction. LOS is an ideal condition for a wireless transmission because the propagation challenge only comes from weather or atmospheric parameters and the characteristic of its operating frequency. In LOS environment, signal can reach longer distance with better signal strength and higher throughput.

Non-line-of-sight (NLOS) is a condition where a signal from a wireless transmitter passes several obstructions before arriving at a wireless receiver. The signal may be reflected, refracted, diffracted, absorbed or scattered. These create multiple signals that will arrive at a receiver at different times, from different paths, and with different strength. Consequently, wireless systems developed for NLOS environment have to incorporate a number of techniques to overcome this problem and that make the systems more complex than those for LOS. But NLOS capable systems simplify network planning and site acquisition.

In IEEE 802.16j networks, AMC (Adaptive Modulation and Coding) [6] is used to choose the proper modulation scheme according to SINR levels. SINR is the ratio of the signal S to the sum of the noise N and the interference signal I, if the frequency reuse scheme is used; MSs on the border between neighbor transmitting stations have the very low SINR value because the received signals other than the intended signal act as the interference. To solve this co-channel interference problem, we propose a novel transmission scheme which removes the co-channel interference within a cell of MSs located at the area experiencing similar signal strength from the neighbor transmitting stations, namely on the border between neighbor transmitting stations such as BS and RS.

2.2 Spectrum utilization

The frequency spectrum allocated for cellular communications is very limited. The success of today's cellular network is mainly due to the frequency reuse concept. This is why the coverage area is divided into cells, each of which is served by a BS. Each BS (or cell) is assigned a group of frequency bands or channels. To avoid radio co-channel interference, the group of channels assigned to one cell must be different from the group of channels assigned to its neighboring cells. However, the same group of channels can be assigned to the two cells that are far enough apart such that the radio co-channel interference between them is within a tolerable limit. Typically, seven neighboring cells are grouped together to form a cluster, as shown in Fig. 2.1. The total available channels are divided into seven groups, each of which is assigned to a cell. In Fig.2.1, the cells marked with the same number have the same group of channels assigned to them. Furthermore, the cells marked with different numbers must be assigned different groups of channels.

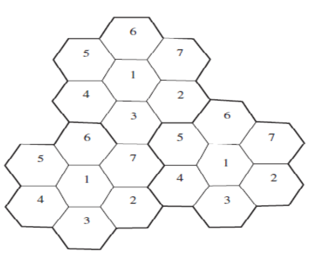

Fig.2.2. Frequency reuse

The reuse distance, D is calculated as;

$D = R\sqrt{3N}$ (2.1)

Where R is the cell radius and N is the number of cells per cluster. Cells may vary in radius in the ranges (1 km to 30 km). The boundaries of the cells can also overlap between adjacent cells and large cells can be divided into smaller cells.

The frequency reuse factor is the rate at which the same frequency can be used in the network. It is 1/K (or K according to some books) where K is the number of cells which cannot use the same frequencies for transmission. Common values for the frequency reuse factor are 1/3, 1/4, 1/7, 1/9 and 1/12 (or 3, 4, 7, 9 and 12 depending on notation).

In case of N sector antennas on the same base station site, each with different direction, the base station site can serve N different sectors. N is typically 3. A reuse pattern of N/K denotes a further division in frequency among N sector antennas per site. Some current and historical reuse patterns are 3/7 (North American AMPS), 6/4 (Motorola NAMPS), and 3/4 (GSM).

If the total available bandwidth is B, each cell can only use a number of frequency channels corresponding to a bandwidth of B/K, and each sector can use a bandwidth of B/NK.

Co-channel interference -Co-channel interference or crosstalk from two different radio transmitters using the same frequency. There can be several causes of co-channel radio interference calculation.

The key characteristic of a cellular network is the ability to re-use frequencies to increase both coverage and capacity. As described above, adjacent cells must use different frequencies; however there is no problem with two cells sufficiently far apart operating on the same frequency. The elements that determine frequency reuse are the reuse distance and the reuse factor.

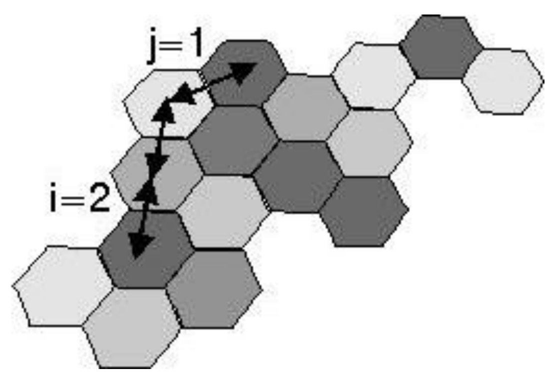

Fig.2.3. Frequency reuse calculation

Frequency reuse calculation is shown in Fig.2.3 in which i=2 and j=1 represents the co-ordinates of the cell. Frequency Reuse is the core concept of cellular mobile radio, Users in different geographical areas (in different cells) may simultaneously use the same frequency. Frequency reuse

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drastically increases user capacity and spectrum efficiency. Frequency reuse causes mutual interference.

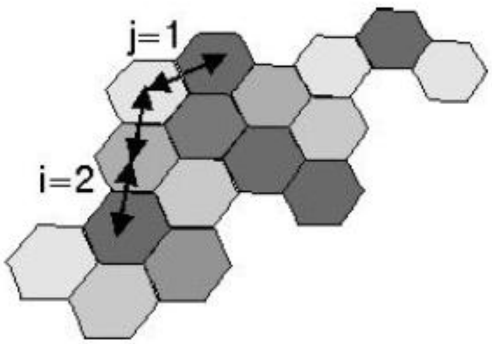

Fig.2.4. Frequency re use distance calculation

Frequency reuse distance calculation is shown in Fig.2.4 in which i=2 and j=1 represents the co-ordinates of the cell. It is used to calculate the reuse distance.

Distance between cell centers
$=\sqrt{3} \times$ cell radius

Reuse distance

$$R_u = \sqrt{i^2 + j^2 + 2ij\cos\frac{\Pi}{3}}\sqrt{3}\,R$$

Where R=cell radius
R_u=reuse distance

In the orthogonal allocation scheme [1], BS or RS transmits two new packets during two slots and MSs suffer little co-channel interference since frequency bands are not reused. However, the system throughput is lower due to no reuse of frequency bands. Two new packets are sent from each RS or BS in overlapped allocation scheme, however, the co-channel interference degrades the SINR for the MSs on the border between two transmitting stations so severely that the total throughput is lower than our scheme. Our scheme reuses frequency bands as the overlapped allocation, but applies a simple interference cancellation scheme to only those MSs which could benefit from the scheme.

3 SIMULATION RESULTS

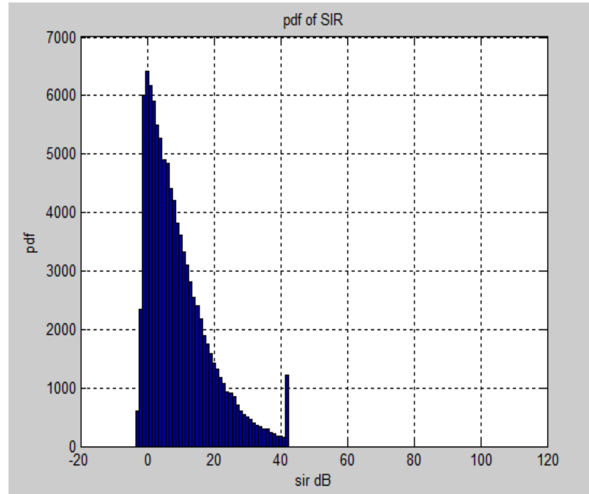

Fig 3.1Histogram of SIR while N=1, n=4

In the fig 3.2, as the number of user increased, the SIR at the receiving station also increased for the value of N=3, n=4.
In the fig 3.3, as the number of user increased, the SIR at the receiving station also increased for the value of N=3, n=4. The histogram shows the average increase in SIR with the increase in N. the result shows when N is larger, the distance between the cluster and the cell experiencing co-channel interference is large which in turn makes the less co-channel interference.

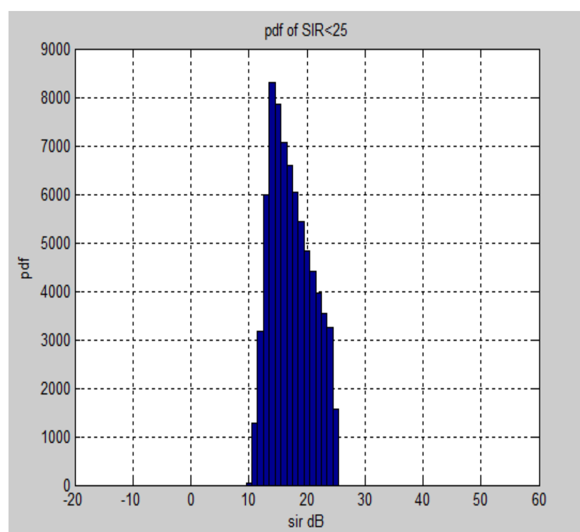

Fig 3.2Histogram of SIR while N=3,n=4

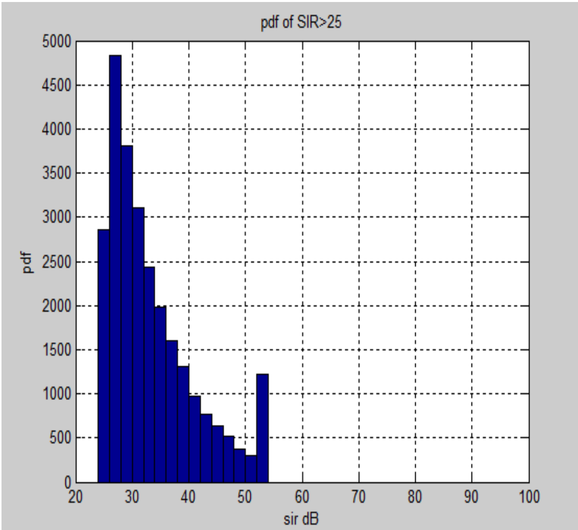

Fig 3.3 Histogram for SIR while N=3,n=4

For a constant cluster size N, the path loss exponent (n) is large which results in large SIR. Since when n is changing, the co-channel interference power is reduced much more than the signal power. Even though the system will lose more power, the SIR is becomes larger.

4 CONCLUSION

This project gives the co-channel interference cancellation in wireless cellular networks. In IEEE 802.16j networks, the allocation scheme that relay stations use the same frequency bandwidth as base station causes the co-channel interference within a cell because all the transmitting stations use the same frequency bandwidth. While the co-channel interference cancellation scheme resolves this co-channel interference problem, the systems signal to interference is greatly improved and the thus signal is transmitted effectively. Further delay performance can be analyzed. And coverage area can be further increased by increasing number of hops.

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