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Inter-Cell Interference in Relay Networks

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Abstract **– Inter-cell Interference (ICI) in multi-cell wireless networks is a major limitation in the performance of these networks. The number of sources of ICI increases in the relay-based wireless networks due to an increase in the number of transmitting nodes in the form of relays. In this paper, we analyze, highlight and briefly describe the effects of ICI in relay networks under different relaying topologies. Our analysis is focused on both One-way relaying (OWR) and Two-way Relaying (TWR) networks with Amplify and Forward (AF) protocol. Furthermore, two types of AF-based TWR are known TWR-Analog Network Coding (ANC) and TWR- Time Division Broadcast (TDBC) protocols are also considered. Simulation analysis on ICI in both OWR and TWR networks is done using MATLAB platform.**

Index Terms **– Relay Networks, Inter-cell Interference, Relay Protocols, Cooperative Network, Multi-cell Networks.**

I. INTRODUCTION

Future wireless communication systems require the use of advanced technologies to effectively enhance the utilization of radio resources. Resource management in wireless systems is crucial to achieve the best system performance. Most of the initial work on Orthogonal Frequency Division Multiplexing (OFDM)-based relay network is focused on a single-cell scenario to provide the basic ideas of allocating resources to maximize the local performance gain. There are few works on multi-cell interference in relay networks [1][2][3][4].

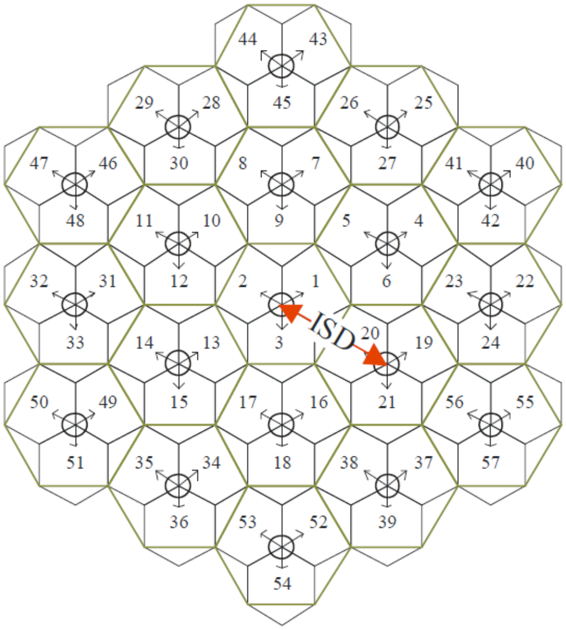
In [1], inter-cell relay cooperation in forming the uplink precoders to maximize the Signal to Noise Ratio/ Signal-to-Interference-Noise Ratio (SINR) is investigated and its transmission rate is evaluated for a linear 3 cell topology. The authors in [2] have proposed a user pairing control method for multi-cell shared multi-user MIMO relay system. In their method, the RT is set on the cell boundary and multiple users located on the adjacent cells make pair for relay transmission. In [3] authors try to transform the non-convex optimization problem to a convex problem by relaxing the multi-cell interference to a limited Interference threshold and, then solving the relaxed convex problem which leads to a suboptimal solution. In [4] authors tried to solve the same problem in [3] but in a multi-cell relayed network which by relaxing the instant interference to a limited interference. In [5], author investigate the resource allocation in multi-cell downlink network using frequency reuse with various transmission modes.

In our previous works [6][7] we also focus on the single-cell scenario where Intra-cell interference and MUI are of our interest. However, in next generation wireless networks, a high frequency reuse factor and small cell size will be necessary in order to achieve higher data rate; and these lead to severe ICI. In reality, ICI severely degrades the system performance and hence should be considered in the resource allocation process. Some work on Inter-cell interference can be found in [8]–[14]

This paper is organized as follows: In Section-II ICI analysis is presented in different relaying techniques. Section-III highlights the simulation environment and parameters while simulation results are presented in Section-IV followed by conclusions in Section-V.

II. ICI ANALYSIS IN RELAYING NETWORKS

Consider a fixed relay based multi-cell OFDM wireless network. Base stations are placed in a regular grid, following the hexagonal layout as described in [8]. A basic hexagonal layout with three cells per site is shown in Fig. 1. The ICI typically involves Mobile Terminals (MTs) in neighbouring cells or sectors being scheduled on the same Resource Block (RBs) or Sub-carrier. The transmission rate of MTs can be degraded due to ICI, especially the MTs present at the edges of cells.



ISD= Inter-Site Distance

Fig. 1 Sketch of Base Coverage Cell Layout without Relay Nodes[15]

Let us consider an example of three adjacent cells of three sites. By considering Cell 1 as the target cell, we investigate the interference signals from other two neighbouring cells in both One-way relaying (OWR) and Two-way Relaying (TWR) networks with Amplify and Forward (AF) protocol.

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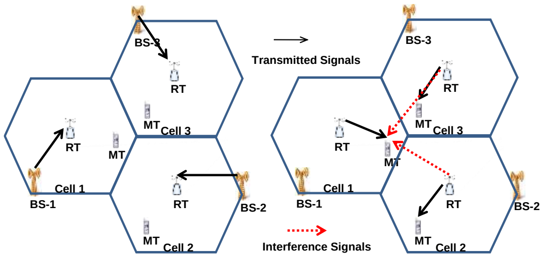
Table 1. List of Notations

Symbol	Definition
M	Number of Mobiles Terminals (MTs)
R	Number of Relay Terminals (RTs)
K	Number of Resource Blocks (RBs)
$P_{x,m}^{k}$	Transmission Power of x to m^{th} MT on k^{th} RB
P_{T}^{k}	Total Transmission power for k^{th} RB
$h_{xy,m}^{k}$	Channel Gain form x to y for m^{th} MT on k^{th} RB
σ_{x}^{2}	Noise Power at x
g_{m}^{k}	Scaling/Amplification Factor for m^{th} MT on k^{th} RB
R_{x}	Instantaneous Throughput for x user over the k^{th} RB
γ	Signal to Noise Ratio/ Signal-to-Interference-Noise Ratio

A. *ICI in OWR Networks*

In OWR networks, two time slots are required in each phase for the MT and the BS to exchange information when relays are working in half duplex mode. In OWR, the spectral efficiency is lost as compared to full-duplex relaying. From a practical point of view, half-duplex relaying is always preferred over full-duplex operation even with this loss of spectral efficiency [16].



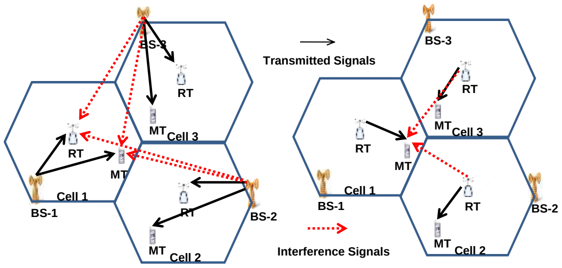
(a) The First Phase (b) The Second Phase

Fig. 2 Multi-Cell OWR Downlink Transmission without the Direct Link

Usually it is assumed that a dedicated link can be established between a Base station (BS) and a fixed Relay Terminal (RT). Thus ICI can be avoided in this link in the multi-cell scenario. Therefore, there will be no ICI in the first phase if only the relay link is being used for transmission, as shown in Fig. 2. On the contrary, there will be ICI in the first phase if the direct link between BS and MT is being used as shown in Fig. 3 Keeping in view the ICI signals in the first and second phases, mathematically, the SINR for the first case when there is no direct communication can be written as:

$$\gamma_1^k = \frac{{g_m^k}^2 P_{B,m}^k \left|h_{BR,m}^k\right|^2 \left|h_{RM,m}^k\right|^2}{\sigma_M^2 + {g_r^k}^2 \left|h_{RM,m}^k\right|^2 \sigma_R^2 + \sum_{i=1}^{I} P_{R,i}^k \left|h_{RM,i}^k\right|^2} \qquad (1)$$

where g_m^k is the scaling factor as given in [17] and $\sum_{i=1}^{I} P_{R,i}^k \left|h_{RM,i}^k\right|^2$ represents the interference signals in the second phase from all I neighboring cells. The $P_{R,i}^k$ is the transmission power of RT in i^{th} neighboring cell while $h_{RM,i}^k$ is the channel gain between RT in the i^{th} cell and the MT in target cell. From Fig. 3 it is clear that to include the direct link transmission; we also need to consider ICI signals on both RT and MT in the first phase of transmission. Using $\sum_{i=1}^{I} P_{B,i}^k \left|h_{BR,i}^k\right|^2$ and $\sum_{i=1}^{I} P_{B,i}^k \left|h_{BM,i}^k\right|^2$ the interference signals in the first the phase from BS to RT and MT in the target cell respectively, the SINR for this transmission can be calculated as (2):



(a) The First Phase (b) The Second Phase

Fig. 3 Multi-Cell OWR Downlink Transmission with the Direct Link

The $P_{B,i}^k$ represents the transmission power of BS in i^{th} neighboring cell. The $h_{BR,i}^k$ is the channel gains between BS in the i^{th} cell and the RT in target cell while $h_{BM,i}^k$ is the channel gains between BS in the i^{th} cell and the MT in target cell. The amplification factor g_m^k with interference signals received at RT for m^{th} MT is given as (3):

$$\gamma_2^k = \frac{{g_m^k}^2 P_{B,m}^k \left|h_{BR,m}^k\right|^2 \left|h_{RM,m}^k\right|^2}{\sigma_M^2 + {g_r^k}^2 \left|h_{RM,m}^k\right|^2 \sigma_R^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{B,i}^k \left|h_{BR,i}^k\right|^2 \left|h_{RM,m}^k\right|^2 + \sum_{i=1}^{I} P_{R,i}^k \left|h_{RM,i}^k\right|^2} + \frac{P_{B,m}^k \left|h_{BM,m}^k\right|^2}{\sigma_M^2 + \sum_{i=1}^{I} P_{B,i}^k \left|h_{BM,i}^k\right|^2} \qquad (2)$$

$$g_m^k = \sqrt{\frac{P_{\mathrm{R},m}^k}{P_{\mathrm{B},m}^k \left|h_{\mathrm{BR},m}^k\right|^2 + \sum_{i=1}^{I} P_{\mathrm{B},i}^k \left|h_{\mathrm{BR},i}^k\right|^2 + \sigma_{\mathrm{R}}^2}} \tag{3}$$

$$\gamma_m^k(ANC) = \frac{{g_m^k}^2 P_{\mathrm{B},m}^k \left|h_{\mathrm{BR},m}^k\right|^2 \left|h_{\mathrm{RM},m}^k\right|^2}{\sigma_M^2 + {g_r^k}^2 \left|h_{\mathrm{RM},m}^k\right|^2 \sigma_{\mathrm{R}}^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{M,i}^k \left|h_{\mathrm{MR},i}^k\right|^2 \left|h_{\mathrm{RM},m}^k\right|^2 + \sum_{i=1}^{I} P_{\mathrm{R},i}^k \left|h_{\mathrm{RM},m}^k\right|^2} \tag{4}$$

$$\gamma_b^k(ANC) = \frac{{g_m^k}^2 P_{M,m}^k \left|h_{\mathrm{RB},m}^k\right|^2 \left|h_{\mathrm{MR},m}^k\right|^2}{\sigma_B^2 + {g_r^k}^2 \left|h_{\mathrm{RB},m}^k\right|^2 \sigma_{\mathrm{R}}^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{M,i}^k \left|h_{\mathrm{MR},i}^k\right|^2 \left|h_{\mathrm{RB},m}^k\right|^2 + \sum_{i=1}^{I} P_{\mathrm{RB}}^k \left|h_{\mathrm{RB},i}^k\right|^2} \tag{5}$$

$$g_m^k = \sqrt{\frac{P_{\mathrm{R},m}^k}{P_{\mathrm{B},m}^k \left|h_{\mathrm{BR},m}^k\right|^2 + P_{M,m}^k \left|h_{\mathrm{MR},m}^k\right|^2 + \sum_{i=1}^{I} P_{i,m}^k \left|h_{i,r}^k\right|^2 + \sigma_{\mathrm{R}}^2}} \tag{6}$$

$$\gamma_{m,r}^k(\mathrm{TDBC}) = \frac{{g_m^k}^2 P_{\mathrm{B},m}^k \left|h_{\mathrm{BR},m}^k\right|^2 \left|h_{\mathrm{RM},m}^k\right|^2}{\sigma_M^2 + {g_r^k}^2 \left|h_{\mathrm{RM},m}^k\right|^2 \sigma_{\mathrm{R}}^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{\mathrm{BR},i}^k \left|h_{\mathrm{BR},i}^k\right|^2 \left|h_{\mathrm{BR},m}^k\right|^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{M,i}^k \left|h_{\mathrm{MR},i}^k\right|^2 \left|h_{\mathrm{RM},m}^k\right|^2 + \sum_{i=1}^{I} P_{\mathrm{R},i}^k \left|h_{\mathrm{RM}}^k\right|^2} \tag{7}$$

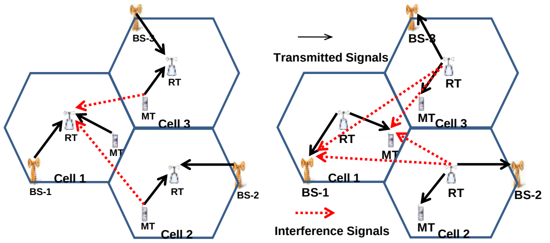
$$+ \frac{P_{\mathrm{B},m}^k Z}{1 + I_{BM,i}}$$

$$g_m^k = \sqrt{\frac{P_{\mathrm{R},m}^k}{P_{\mathrm{B},m}^k \left|h_{\mathrm{BR},m}^k\right|^2 + P_{M,m}^k \left|h_{\mathrm{MR},m}^k\right|^2 + {g_r^k}^2 \sum_{i=1}^{I} P_{\mathrm{BR},i}^k \left|h_{\mathrm{BR},i}^k\right|^2 + \sum_{i=1}^{I} P_{i,m}^k \left|h_{i,r}^k\right|^2 + \sigma_{\mathrm{R}}^2}} \tag{8}$$

B. *ICI in TWR Networks*

The two types of TWR have been proposed in the literature [18] to overcome the spectral loss in OWR. These two types of AF-based TWR are known TWR-Analog Network Coding (ANC) and TWR- Time Division Broadcast (TDBC) protocols, respectively [19].The uplink and downlink transmissions occur simultaneously in TWR [18]. Therefore, unlikely OWR, the ICI from neighbouring cells occurs in both hops of transmission even if we consider a dedicated link between BS and RTs. During the first phase in TWR-ANC, the ICI is received from MTs of others cells scheduled on the same RBs. There will be no ICI signal from BSs of other cell as the transmission between BSs and RTs are over dedicated links as shown in Fig. 4(a). While in the second phase, ICI signals are received by both BS and MT in the target cell due to the broadcast nature of the signal from RTs as shown in Fig. 4(b). Therefore, the SINRs at MT and BS in the target cell can be written as (4) and (5) while the amplification factor g_m^k with interference signals received at RT is given as (6).

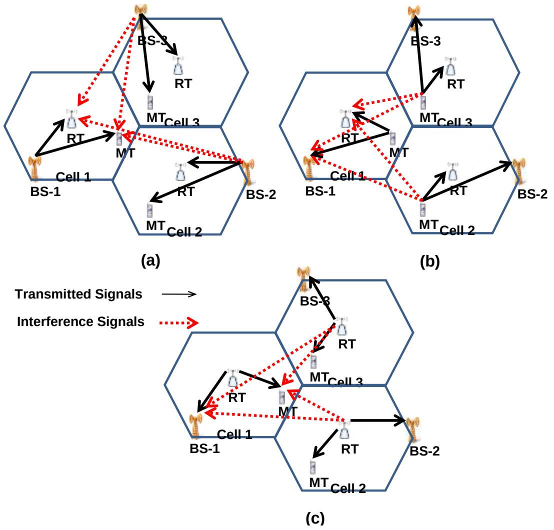
On the other hand, in TWR-TDBC networks, there is more ICI present as shown in Fig. 5. As we know, the TDBC transmission takes three time slots to complete the information transfer from source to destination; and the ICI presents in each time slot.



(a) The First Phase (b) The Second Phase

Fig. 4 Multi-Cell TWR-ANC Transmission

During the first phase, ICI arises from neighbouring BSs to target RT and target MT, while in the second phase neighbouring MTs scheduled on the same RBs produce ICI signal toward both target BS and target RT. In the third phase, when RTs are broadcasting the amplified signals, the neighbouring RTs produce ICI in target cell on both BS and MT. Keeping in view all these interferences, the received SINR at MT in target cell can be expressed as (7) and the amplification factor is given in (8).



(a) (b) (c)

Fig. 5 Multi-Cell TWR-TDBC Transmission

III. SIMULATION SETUP AND PARAMETERS

A. *Cellular Architecture*

The cellular network consisting of 7 sites is considered for simulation. Each site consists of three hexagonal cells and a RT is added to each cell as shown in Fig. 6. The relays are placed at the middle of each cell. The distance between two BSs is 1 KM.

B. *Propagation Models*

The shadowing and path losses are considered separately. The LOS path loss model is used for BS-RT link as we assume that relays are in LOS of BS which has directional antennas for transmission. The NLOS path loss model is used for RT-MT links. Both path loss models are given as in [15].

$$\begin{aligned} PL\_LOS &= 36.7\log_{10}(d) + 22.7 + 26\log_{10}(f_c)\ \text{dB} \\ PL\_NLOS &= 22.0\log_{10}(d) + 28.0 + 20\log_{10}(f_c)\ \text{dB} \end{aligned} \qquad (9)$$

The simplified model given in (10) is adopted for shadowing loss.

$$L_{\text{shadow}}(m) = \begin{cases} \rho\ \text{dB}, & \text{if } m \text{ is in a shadowed area} \\ 0\ \text{dB} & \text{otherwise} \end{cases} \qquad (10)$$

where ρ is the standard deviation. While shadowing loss is considered at both MT-RT and RT-MT links, no shadowing loss is imposed for the dedicated BS-RT link.

C. *Antenna Configuration*

To take into account the ICI, the antenna pattern for all nodes should be considered. Here we assume that all BSs are equipped with both sectored directional antennas to support LOS transmission between BSs and RTs and omnidirectional antennas for direct transmission between BSs and MTs, while all RTs and MTs are equipped with a single omnidirectional antenna, respectively. Fig. 7 shows the BS antenna pattern for 3-sector cells.

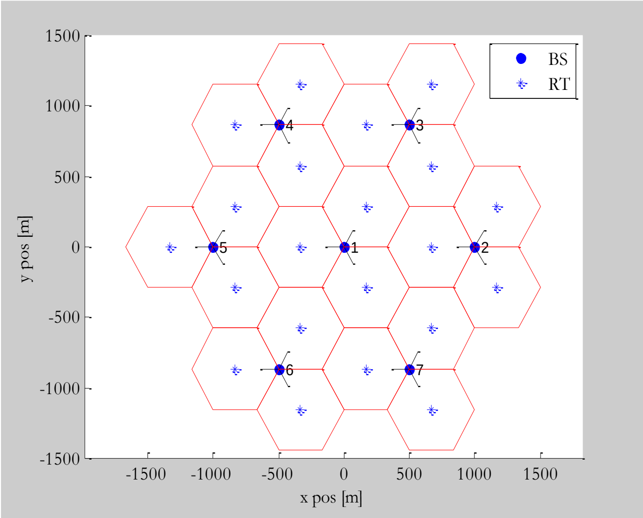


Fig. 6 Simulation Setup for Multi-Cellular Layout with Relays

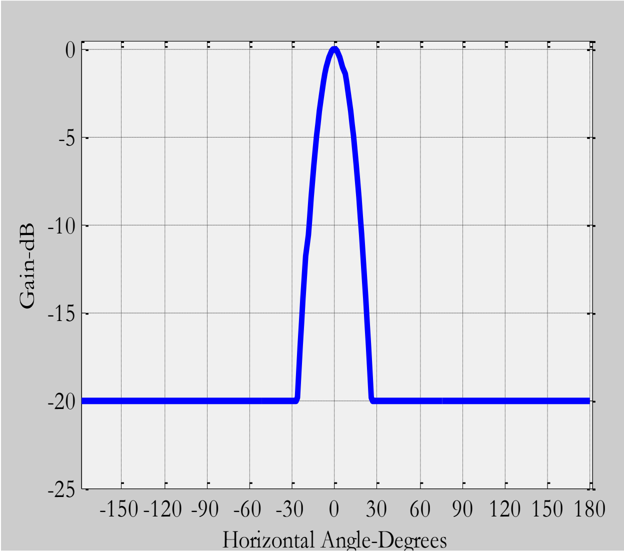


Fig. 7 BS Antenna Pattern [15]

The antenna pattern for sectored antennas as proposed in [8] is given as:

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3\text{dB}}}\right)^2, A_m\right] \qquad (11)$$

where

$A(\theta)$ = Relative antenna gain(dB) in the direction θ;

$-180^\circ \le \theta \le 180^\circ$ is the angle between the direction of interest and the bearing direction of the antenna;

min [.], denotes the minimum function;

$\theta_{3\text{dB}}$ is the 3 dB beamwidth and $\theta_{3\text{dB}} = 70^\circ$;

A_m = 20 dB is the maximum attenuation;

IV. NUMERICAL RESULTS

This section presents the simulation analysis on ICI in both OWR and TWR networks. For OWR we consider only downlink transmission while for TWR both uplink and downlink transmissions are considered simultaneously. Cell 1 of Site 1 is considered as target cell and all other neighboring cells are assumed as interfering cells. A single MT is placed in each cell at the same position for simplicity. Other simulation parameters are given in Table 2.

Fig. 8 shows the ICI analysis on OWR with and without the presence of the direct link between BS and MT during transmission. It is clearly shown that higher transmission rate is achieved with the direct link due to the diversity gain. There are two points to be noted here. The first point is that transmission rate is much degraded due to the presence of ICI, and therefore ICI cannot be neglected in any practical scenario. The second point is that the difference in transmission rate between the case with direct link and that without direct link widens as the number of RBs increases, when ICI is not considered. However, this difference shrinks notably once ICI is taken into account. This is because of the presence of the ICI signals in the first phase of transmission when the direct link is also being used for transmission along with the relay links.

Table 2. Simulation Parameters

Parameters	**Value**
Number of Sites	7
Number of Cells per Site	3
BS-BS Distance	1 Km
Number of RTs per Cell	1
RT-BS Distance	0.5 x Cell Radius
Carrier Frequency	2 GHz
Shadowing for NLOS Link	8.9 dB
OFDM Subcarrier Bandwidth	15 KHz
Number of Subcarrier per RB	12
Noise Power Density	-170 dBm/Hz
BS Max. Tx. Power	46 dBm
RT Max. Tx. Power	37 dBm
MT Max. Tx. Power	15 dBm

Fig. 9 presents an analysis of ICI on TWR network. Both ANC and TDBC protocols are considered. Like in OWR, the ICI degrades the sum-rate in TWR as well. As discussed in the previous Chapter, ANC is an efficient protocol than TDBC in terms of spectral efficiency due to the less number of time slots required to complete the exchange of information between source and destination, and here the same is again verified with and without the presence of ICI.

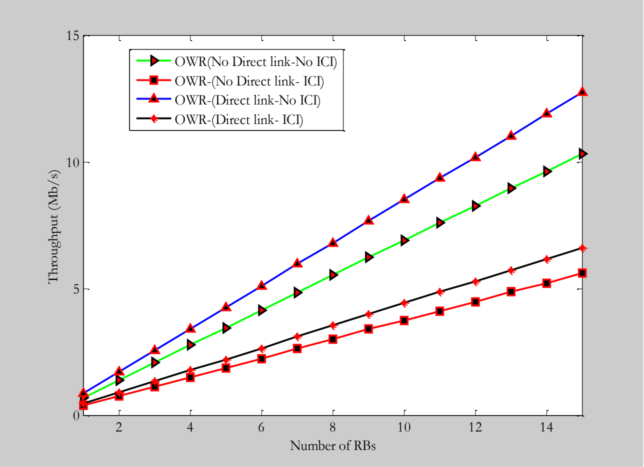


Fig. 8 ICI Analysis on OWR Networks with and without the Direct Link

TDBC protocol experiences more interference than ANC protocol as shown in Fig. 5. Therefore the sum-rate difference between ANC and TDBC protocols increases when ICI is taken into account in TWR networks.

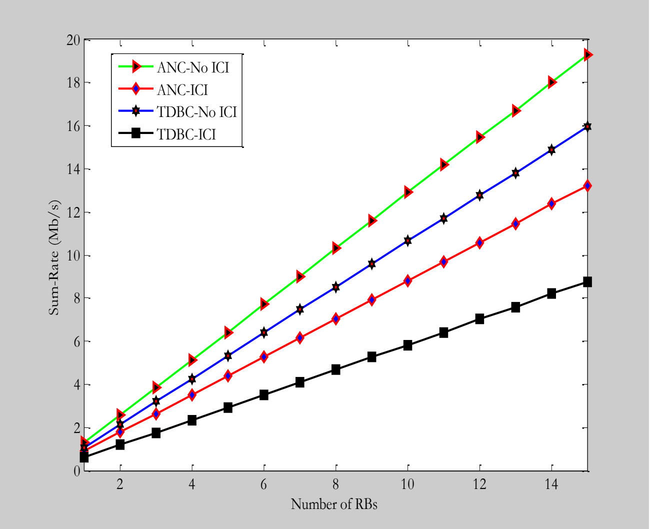


Fig.9 ICI Analysis on TWR Networks with ANC and TDBC Protocols

V. CONCLUSIONS

In this paper, the different ICI cases of relay networks are analysed. Simulation results show that the throughput degrades significantly due to the presence of ICI. For simulation purposes, 7 sites were selected as this is a typical number in many literatures. It makes the comparison easier with our results. It can be observed that the degradation differs slightly with different network relaying techniques and protocols. Based on the ICI levels, appropriate relaying schemes can be adopted. Further investigations will be carried out to mitigate the performance degradation due to ICI. Such work will explore use of efficient resource scheduling algorithms ICI in multi-cell scenarios.

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