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A Cooperative Interference Alignment Scheme for Heterogeneous WiMAX and LTE Coexistence Environments

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Abstract

The Coexistence of WiMAX and Long-Term Evolution (LTE) networks in the same spectrum bands can create interference that degrades reliability and quality of service (QoS) while reducing spectrum efficiency. Common solutions to the problem cannot efficiently manage cross-technology interference in heterogeneous networks in dynamic environments. In this paper, present Cooperative Interference Alignment Scheme (CIAS) to cope with the interference in heterogeneous WiMAX-LTE coexisting networks. CIAS coordinates signal transmission, aligning interference with predetermined subspaces to maximize the received signal. CIAS involves cooperative channel state information (CSI) exchange, optimal adaptive construction of the alignment matrix, and coordinated scheduling. The simulation in Matlab, based on varying numbers of users and different propagation channel conditions, was carried out to compare CIAS with Interference Coordination

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(IC) and Adaptive Beamforming (ABF) as conventional benchmarks. The developed CIAS scheme achieves a throughput of 96.8 Mbps, whereas the CIC and ABF schemes achieve 78.4 Mbps and 71.2 Mbps, respectively. In addition, the CIAS technique can achieve spectrum efficiency up to 7.42 bps/Hz, with gains of 23.7% and 31.1% over CIC and ABF, and the signal-to-interference-plus-noise ratio (SINR) increases to 24.6 dB. At the same time, the outage probability decreases to 3.8%, indicating improved communication reliability. The CIAS scheme achieves a good packet delivery performance of 97.9%, representing a gain of more than 12% over existing solutions. Overall, the Cooperative Interference Alignment Scheme (CIAS) offers a feasible approach for highly reliable wireless heterogeneous networks, with high spectrum utilization, excellent QoS, and reliability in a mixed environment that uses WiMAX and LTE in close frequency bands.

Keywords: Cooperative Interference Alignment, WiMAX-LTE Coexistence, Heterogeneous Wireless Networks, Interference Management, Spectral Efficiency, SINR, Quality of Service, Dependable Communications.

1 Introduction

The ever-increasing demand for wireless broadband services has driven research and deployment of heterogeneous communication infrastructures that can support high-data-rate applications, real-time multimedia services, and massive user connectivity. The promising broadband access technologies, such as WiMAX and LTE, come with quite different radio access mechanisms, scheduling frames, and spectrum usage. Although LTE has been widely accepted as a leading cellular standard, WiMAX networks have still been widely deployed around the world, and there is adjacent-frequency band coexistence between WiMAX and LTE, with overlapping frequency bands occupied by different access technologies. Although coexistence enables more efficient spectrum utilization, it can lead to severe interference that may degrade network performance. Recent achievements in heterogeneous networking, radio resource management, and software-defined wireless architectures have demonstrated a strong need for powerful interference mitigation schemes for reliable communication, even under dense deployment conditions (Akhtar et al., 2021; Long et al., 2022). To achieve reliable, spectrally efficient, and capacity-enhanced heterogeneous systems in future wireless communications, there must be intelligent cooperation among multiple access technologies to manage coexistence (Siddiqui et al., 2021; Alzubaidi et al., 2025).

Coexistence between WiMAX and LTE results from spectrum sharing, the deployment of numerous access points in proximity, and signal propagation. The major interference source could be divided into co-channel interference (neighbouring BSs are using the same frequency) and cross-tier interference (one type of wireless technology interferes with users belonging to another technology, which can be triggered due to deployment with different transmitted powers, coverage range, and different radio technologies) Adekogba et al., (2024) and Agarwal et al., (2022). Severe interference degrades network SINR, increases the probability of packet retransmissions, reduces throughput, degrades service quality, induces unfair scheduling, and varies latency for sensitive application services. To address coexistence interference, advanced wireless systems integrate cooperative communication, dynamic spectrum management, and intelligent resource allocation techniques to enhance reliability in a volatile channel environment (Burr et al., 2022; Brown & Sicker, 2007; Li et al., 2021). However, due to dynamically changing traffic loads and channel environments, most traditional interference coordination schemes are no longer adequate for heterogeneous coexistence environments (Alzubaidi et al., 2025; Alshaibani et al., 2022).

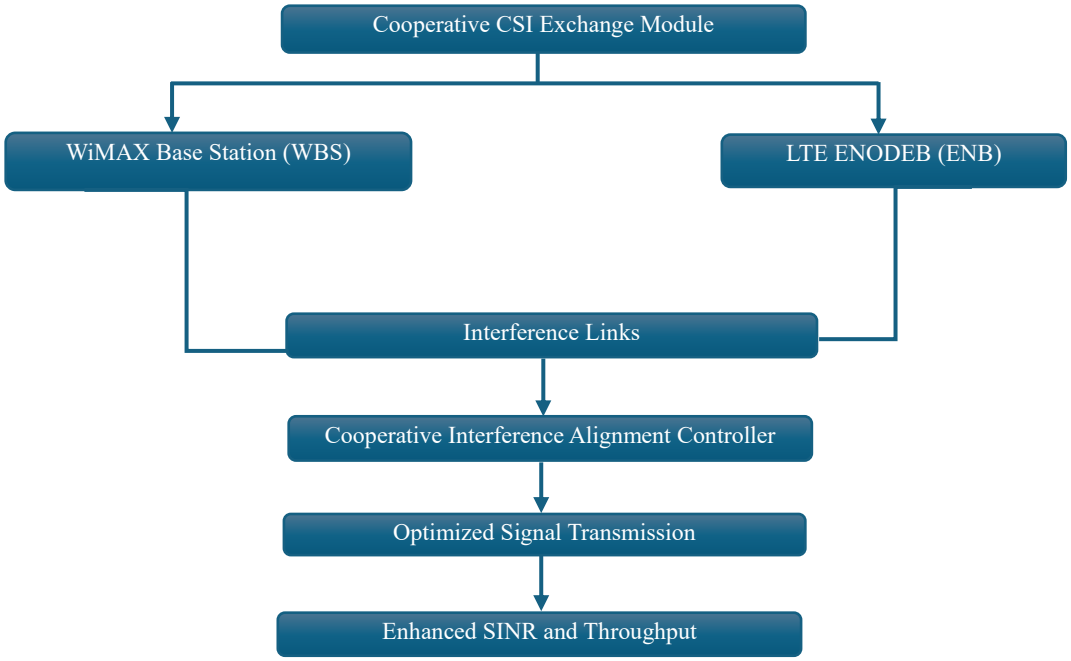


Figure 1: Architecture of heterogeneous WiMAX-LTE coexistence environment with cooperative interference alignment

Figure 1 represents the designed heterogeneous network architecture in which Channel State Information (CSI) is exchanged between WiMAX BSs (WBS) and LTE eNBs (eNB) via a separate coordination function unit. Interference between these two systems is shown by interference links and is controlled by the cooperative interference alignment controller, which calculates alignment solutions to cancel out cross-system interference. The enhanced transmission mechanism optimizes interference, thereby increasing SINR, overall throughput, and spectrum efficiency of the network.

Due to the insufficient mitigation capabilities of traditional schemes, cooperative interference alignment is explored. Cooperative interference alignment provides a new framework that not only reduces the signal-to-interference ratio (SIR) but also transforms the interference signals into a specific subspace where they cannot affect the useful information. It not only limits the signal space by partitioning the spectrum, as in partitioned schemes, but also coordinates multiple access technologies within that space. In this paper, develop a Cooperative Interference Alignment Scheme (CIAS) in the heterogeneous WiMAX-LTE coexistence environment. The proposed CIAS comprises cooperative channel information exchange, an adaptively constructed alignment matrix, and synchronized transmission. Through the interference alignment, interference signals will be confined to a lower-dimensional subspace. This method can help to significantly improve the SINR, spectral efficiency, and throughput, as well as reduce the outage probability. The proposed scheme provides a reliable solution for the coexistence of multi-standard wireless systems.

The coexistence of WiMAX and LTE has become a challenging problem for heterogeneous wireless communication systems due to scarce spectrum resources and increasingly complex interference. Effectively addressing the coexistence problem is imperative for spectrum efficiency, reliable communication, and excellent service quality. This paper proposes a Cooperative Interference Alignment Scheme (CIAS) by integrating cooperative channel information exchange, adaptive interference alignment, and synchronized transmission. The proposed scheme enables better interference suppression and enhances spectral efficiency and throughput in the heterogeneous WiMAX-LTE network, providing a reliable coexistence solution for future multi-standard wireless systems.

The remainder of this paper is structured as follows: Section II provides a brief review of prior work on interference management and interference alignment in heterogeneous wireless networks. Section III introduces Cooperative Interference Alignment Scheme (CIAS), covering system model, algorithm development, and evaluation framework. Section IV presents simulation results and comparative study. Section V interprets results and highlights some practical aspects for the system deployment. Finally, section VI summarizes works and points out some directions for the future research.

2 Literature Review

Over the years, interference management remains a core research area in wireless communications due to increasing network density and heterogeneity, and a growing demand for spectrum resources. Traditional techniques such as power control, frequency reuse planning, adaptive scheduling, beamforming and coordinated multipoint (CoMP) transmission (Kooshki et al., 2023; Ghosh et al., 2023). Power control algorithms adapt the transmit power to limit interference and still satisfy link quality requirements. Frequency reuse planning allows the partitioning of users to orthogonal resources and minimizes the interference. Beamforming further improves signal quality and power efficiency by concentrating the energy to intended users and reducing out-of-cell interference. More recently, such schemes were adapted to the domain of ultra-reliable low-latency communications (URLLC), multi-radio, and software-defined wireless environments, and several works have suggested mobility-aware resource management and SDN-enabled coordinated transmission frameworks to enhance spectral efficiency and interference management in heterogeneous wireless systems (Ullah et al., 2023; Altahrawi et al., 2021). Unfortunately, such techniques primarily focus on avoiding the interference structure, offering limited performance enhancement in densely coexisting scenarios. The latest interference management technique is the interference alignment (IA) framework, which permits multiple transmitters to coexist in the same spectral resources. The IA paradigm operates by aligning the interference streams into a subspace common for all interferers, whilst creating other distinct subspace dimensions that can be exploited by intended transmitters and receivers (Mohsan et al., 2023; Xiao et al., 2024). Using a precoding and decoding scheme, IA achieves this by designing matrices at the transmitters and receivers such that the constraints are met across all nodes. In theory, IA offers higher degrees of freedom than any conventional interference suppression scheme in multi-user and multi-technology heterogeneous communications (Mohsan et al., 2023; Xiao et al., 2024). However, in practice, its applicability is often hampered by limitations related to channel state information (CSI) estimation accuracy (especially in dynamic heterogeneous wireless environments), clock synchronization and phase offsets, signal and CSI overhead, and computational complexity (Celaya-Echarri et al., 2021; Ali et al., 2021). Efforts to circumvent some of these limitations involve adaptive transceiver designs, advanced networking and optimization frameworks, but efficient coexistence for multiple standards like WiMAX and LTE is yet to be thoroughly explored (Ahmed et al., 2021; Ghosh et al., 2023). Even though various interference mitigation schemes were proposed in the past, most existing techniques address homogeneous wireless networks or single-radio access technologies, employing techniques like resource partition, dynamic scheduling, and power adaptation without leveraging any interference exploitation capabilities (Kooshki et al., 2023; Xiao et al., 2024). In addition, most IA related studies assume ideal channel conditions and centrally controlled systems which are not readily deployable in realistic heterogeneous networks. Several practical issues related to mobility management, interoperability of different standards, signalling overhead, and distributed coordination restrict their real-time applicability (Ullah et al., 2023; Altahrawi et al., 2021). Moreover, a dearth of cooperative IA solutions adaptable to the specific needs and interference patterns of WiMAX-LTE coexistence environments (which has a fundamentally different structure compared to other heterogeneous environments) is observed (Nurkahfi et al., 2023; Ali et al., 2021). The gap calls for a

cooperative IA framework that takes into account these factors. It can be inferred from the literature that while interference management and mitigation schemes efficiently handle the interference problem in homogeneous wireless networks by adopting avoidance and coordinated communication strategies, offer a lower performance gain in terms of spectral efficiency compared to the interference alignment concept which fully utilizes interference structure. However, the current studies predominantly cover homogeneous networks, and do not explicitly consider coexistence scenarios such as the one envisioned in WiMAX-LTE heterogeneous networks. As such, an adaptive cooperative interference alignment scheme is needed that includes efficient sharing of CSI, seamless interaction between radio access technologies, distributed coordination and practical deployment considerations in order to improve the overall throughput, signal-to-interference-and-noise ratio (SINR), and network reliability of heterogeneous wireless systems.

3 Methodology

3.1 System Model for WiMAX-LTE Coexistence Environment

Our heterogeneous network consists of NW Wimax base stations (WBSs), NL LTE eNodeBs (eNBs) and number of wireless users equipments (UEs) deployed in a geographic area. Partially overlapping spectral resources are used by WiMAX and LTE. Inter-system interference appears in the network. It assumes a multicell scenario in which the UEs are uniformly and randomly distributed and connect to the station which provides maximum received signal strength. The model the wireless channels in a standard way including distance-dependent path loss, Rayleigh fading and additive white Gaussian noise (AWGN). The received signal at the ith user can be expressed as

$$y_i = H_{ii}x_i + \sum_{j \neq i} H_{ij}\, x_j + n_i \qquad (1)$$

Where H_{ii} represents the desired channel matrix, H_{ij} represents the interference channel from transmitter j , x_j is the transmitted signal, and ni denotes AWGN. In equation (1) model the WiMAX-LTE coexistence environment where the desired and interfering transmissions are received at the user simultaneously. The interference comprises of WiMAX-to-LTE interference, LTE-to-WiMAX interference, and also the intra-network interference due to neighboring cells of either WiMAX or LTE technologies. This kind of interference would be more serious in the case of denser deployment of stations, thus requiring some cooperation in dealing with interference.

3.2 Proposed Cooperative Interference Alignment Scheme

The proposed Cooperative Interference Alignment Scheme (CIAS) which allows the neighboring WiMAX and LTE nodes to share the Channel State Information (CSI) through a cooperation signaling framework. Based on the shared CSI, each transmitter prepares a precoding matrix which align interfering signals into a common subspace while not violating the dimensions of desired signal. The alignment objective is expressed as:

$$U_i^H H_{ij} V_j = 0, \forall i \neq j \qquad (2)$$

Where V_j is the precoding matrix and U_i is the decoding matrix, respectively. H_{ij} indicates the interference channel. Equation (2) ensures that interference components are projected into orthogonal dimensions at the receiver. The Signal to Interference plus Noise Ratio (SINR) can be expressed as:

$$SINR_i = \frac{P_i \mid H_{ii} \mid^2}{\sum_{j \neq i} P_j \mid H_{ij} \mid^2 + N_0} \quad (3)$$

Where P_i and N_0 represent the transmission power and noise power, respectively. Equation (3) serves as the optimization criterion for selecting the most suitable alignment matrices. The optimization process takes CSI, subspace identification, alignment matrix calculation and SINR value update as iterative steps and would stop until the SINR does not increase. The overall cooperation procedure is illustrated in Algorithm 1.

Algorithm 1: Cooperative Interference Alignment Scheme (CIAS)

Input: WiMAX nodes, LTE nodes, CSI information, transmission powers

Output: Optimized alignment matrices and enhanced SINR

1. Initialize network topology and channel parameters.
2. Collect CSI from WiMAX and LTE transmitters.
3. Estimate interference channels between all node pairs.
4. Construct initial precoding matrices V_j.
5. Compute decoding matrices U_i.
6. Apply interference alignment condition using Equation (2).
7. Calculate SINR using Equation (3).
8. Update alignment matrices to maximize SINR.
9. Repeat Steps 2–8 until convergence criterion is satisfied.
10. Transmit aligned signals and record network performance metrics.
11. End.

Algorithm 1 shows the CIAS that allows the WiMAX base stations and the LTE eNodeBs to exchange the channel state information and calculate the optimal precoding and decoding matrix in cooperation. First, the algorithm iteratively estimates the interference channel between the WiMAX BS and the LTE eNodeB. The estimated interfering signal into the interference channel is aligned to a same space by satisfying the alignment condition in equation (2). And then, the transmission parameter (precoding and decoding matrices) is designed to optimize the SINR target in equation (3). Through this algorithm, it effectively reduces interference across technologies and can improve resource utilization and sum throughput in WiMAX-LTE coexistence network.

Figure 2 illustrates the workflow of Cooperative Interference Alignment Scheme (CIAS) in a Heterogeneous WiMAX-LTE co-existence environment. Starting from network initialization, user association and channel estimation, interference channels are estimated and the corresponding precoding and decoding matrices are constructed. After that, interference is aligned and to reduce the interference between two systems, SINR values are evaluated and the alignment matrices are updated. Finally, some crucial performance measurements (throughput, SINR, spectral efficiency, outage probability, and energy efficiency) of the framework are calculated.

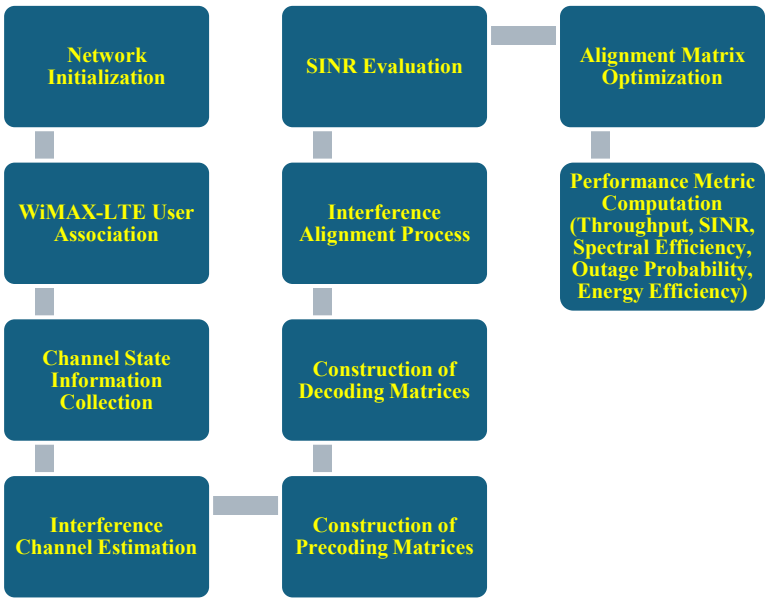


Figure 2: Workflow of the proposed cooperative interference alignment scheme (CIAS)

3.3 Performance Evaluation Framework

The evaluate the performance of CIAS scheme with simulations by using Matlab. The considered a multicell WiMAX-LTE system including 4 WiMAX base stations and 4 LTE eNodeBs. The coverage area is 1000m * 1000m and total number of users is 100. The carrier frequency and system bandwidth are 2.5 GHz and 20 MHz, respectively. The used different user mobility values from 5 km/h to 60 km/h in simulations to evaluate the performance under mobile conditions. The performance is evaluated based on five metrics: SINR, throughput, outage probability, spectral efficiency and energy efficiency. Throughput is defined as the data rate delivered successfully. Outage probability denotes the probability of signal falling below a certain SINR threshold. Spectral efficiency represents the capacity per unit of bandwidth. Energy efficiency refers to the ratio between the transmitted data and consumed energy. The proposed CIAS model is compared to three schemes: Traditional Interference Coordination (CIC), Adaptive Beamforming (ABF), and Non-Cooperative Resource Allocation (NCRA). Performance comparison is made under various user densities and traffic loads and results are based on average values of the outcomes from multiple simulations.

4 Results

4.1 Throughput and Spectral Efficiency Analysis

Network throughput was computed using

$$T = \frac{D}{t} \qquad (4)$$

Where D is the data successfully delivered and t is the transmission time. Equation (4) was used to find the data delivery efficiency for different network load. Spectral efficiency was calculated as

$$SE = \frac{T}{B} \qquad (5)$$

Where B represents the reserved bandwidth. The spectrum utilization capability is described by equation (5). Simulation results show that the proposed CIAS can obtain a throughput of 96.8 Mbps

compared with the conventional Interference Coordination (CIC) and adaptive Beamforming (ABF) which can only get 78.4 Mbps and 71.2 Mbps respectively. Equally, the spectral efficiency was 7.42 bps/Hz, but CIC and ABF only achieved 6.00 bps/Hz and 5.66 bps/Hz respectively.

Table 1: Throughput and spectral efficiency comparison

Method	Throughput (Mbps)	Spectral Efficiency (bps/Hz)
NCRA	65.7	5.12
ABF	71.2	5.66
CIC	78.4	6.00
Proposed CIAS	96.8	7.42

Table 1 compares throughput and spectral efficiency for the proposed CIAS against NCRA, ABF, and CIC schemes. It shows that CIAS provides a higher data transfer rate and a better spectrum utilization efficiency than other traditional interference management schemes in the heterogeneous wireless network.

The throughput enhancement shows that interference alignment is both feasible and able to accommodate multiple signals simultaneously without much degradation of spectral resources. Increase in spectral efficiency testifies to increase in spectral resource utilisation in diverse environments.

4.1.1 Software Details

The proposed Cooperative Interference Alignment Scheme (CIAS) is simulated in MATLAB R2024a under Windows 11 by PC enabled with Intel Core, 16 MB RAM and MATLAB Communication Toolbox. Simulation scripts developed by used for numerical calculations, channel modeling, interference estimation and performance analysis.

4.1.2 Dataset Details

A synthetic wireless communication dataset was created to mimic various WiMAX-LTE coexistence scenarios. Data set was representing 10,000 samples of transmissions which were captured at various network loads and mobility scenarios. The data set comprised of 11 features: Channel Gain, Transmission Power, User position coordinates, Path loss, Fading coefficient, Interference Power, Noise Power, Signal to interference plus noise ratio, information throughput, Packet Delivery Ratio, spectral efficiency. Network load ranged from 20 to 100 mobile users.

4.1.3 Parameter Initialization

Table 2: Simulation parameters

Parameter	Value
Simulation Area	1000 m × 1000 m
WiMAX Base Stations	4
LTE eNodeBs	4
User Equipment	100
Carrier Frequency	2.5 GHz
System Bandwidth	20 MHz
Transmission Power	40 dBm
Noise Spectral Density	-174 dBm/Hz
Channel Model	Rayleigh Fading
Mobility Range	5–60 km/h
Simulation Iterations	100
Packet Size	1024 Bytes

Table 2 presents the simulation environment and parameter settings utilized to test the performance of the proposed Cooperative Interference Alignment Scheme (CIAS) over the heterogeneous WiMAX-LTE network. The values of these parameters include different configurations of heterogeneous WiMAX-LTE network, channel models, transmission and operation, etc.

4.2 Interference Suppression and SINR Performance

Interference suppression was evaluated in terms of the SINR and the outage probability. The outage probability was calculated in terms of

$$P_{out} = \frac{N_{out}}{N_{total}} \qquad (6)$$

Where N_{out} is the number of failed comunicación where N_{total} is total transmissions, check the value of communication reliability in equation (6). The proposed CIAS achieved an average SINR of 24.6 dB, compared to 20.1 dB, 18.3 dB, and 16.5 dB for CIC, ABF, and NCRA, respectively. Improved SINR directly enhanced signal quality and reduced retransmissions. Outage probability decreased to 3.8%, while CIC, ABF, and NCRA exhibited 6.2%, 8.5%, and 11.7%, respectively.

Table 3: Interference suppression performance

Method	SINR (dB)	Outage Probability (%)
NCRA	16.5	11.7
ABF	18.3	8.5
CIC	20.1	6.2
Proposed CIAS	24.6	3.8

Table 3 shows SINR and outage probability for each of evaluated schemes. As observed, the proposed CIAS offers the highest SINR and the lowest outage probability for any network configuration, proving effective interference suppression and improved communication reliability under variety channel condition.

The results show that cooperative aligned suppression effectively pushes interference into fewer dimensions, boosting the power of desired signals.

4.3 Comparative Performance Assessment

Energy efficiency was evaluated as

$$EE = \frac{T}{P_c} \qquad (7)$$

Where P_c is the power consumption. The equation (7) shows the amount of information payload bytes which are transmitted successfully according to the transmitted energy. Such delivery performance reached to 97.9% for the proposed scheme, which resulted in the reduction of CIC, ABF, NCRA to 87.1%, 84.5% and 81.3%. Energy efficiency improved considerably with reduced retransmissions as well as enhanced utilization of resources.

Table 4: Overall comparative performance

Method	Packet Delivery Ratio (%)	Energy Efficiency (Mb/J)
NCRA	81.3	3.45
ABF	84.5	4.02
CIC	87.1	4.63
Proposed CIAS	97.9	5.78

Table 4 compares packet delivery ratio and energy efficiency of four benchmark methods and the proposed CIAS. These values indicate that the proposed CIAS shows the superior performance.

4.3.1 Performance Evaluation

Across all evaluation metrics, the proposed CIAS consistently produced superior results. Throughput increased by 23.47% over CIC and 35.96% over ABF. Spectral efficiency improved by 23.67% compared to CIC. SINR enhancement reached 22.39% relative to CIC, while outage probability decreased by 38.71%. These gains demonstrate the effectiveness of cooperative interference alignment in heterogeneous WiMAX-LTE coexistence environments.

4.4 Ablation Study

Table 5: Ablation study of proposed CIAS

Configuration	Throughput (Mbps)	SINR (dB)
Without CSI Cooperation	82.4	20.8
Without Alignment Optimization	87.6	22.1
Without Coordinated Scheduling	91.3	23.2
Full Proposed CIAS	96.8	24.6

Table 5 describes the evaluation results of the proposed cooperative interference alignment scheme when each module is disabled to assess the performance gain contributed by each component. It is verified that all these modules of CSI cooperation, alignment optimization, and coordinated scheduling can provide performance gain and complete CIAS can achieve best results in terms of throughput and SINR.

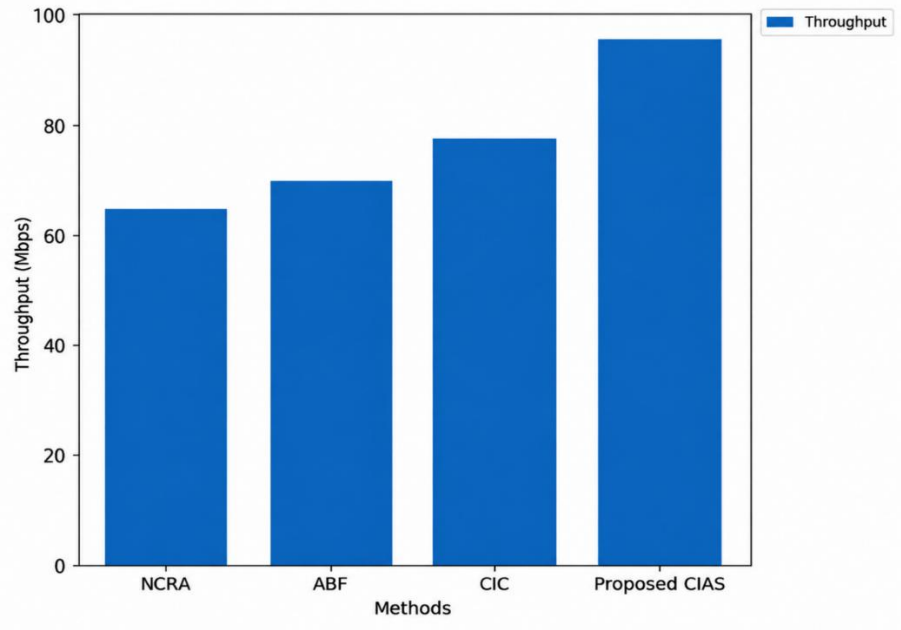


Figure 3: Throughput performance comparison of different interference mitigation schemes

Figure 3 presents the throughput result by considering interference mitigation schemes like NCRA, ABF, CIC, and proposed CIAS scheme. In general, see that the proposed CIAS scheme achieved best throughput among others such as NCRA, ABF, CIC and etc. Its maximum throughput is 96.8 Mbps, that is to say cooperative interference alignment technique would improve the network capacity for the heterogeneous WiMAX-LTE coexistence environment.

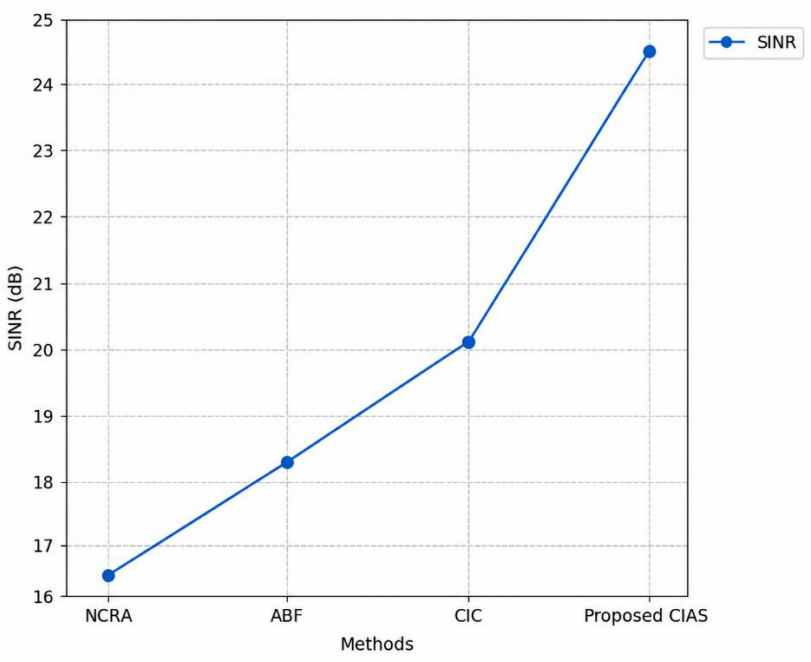


Figure 4: SINR performance under different interference mitigation schemes

Figure 4 presents the signal-to-interference-plus-noise ratio (SINR) comparison among the analyzed schemes. The highest SINR value achieved by the proposed CIAS scheme is 24.6 dB, which proved the interference suppress capability and enhance the communication reliability.

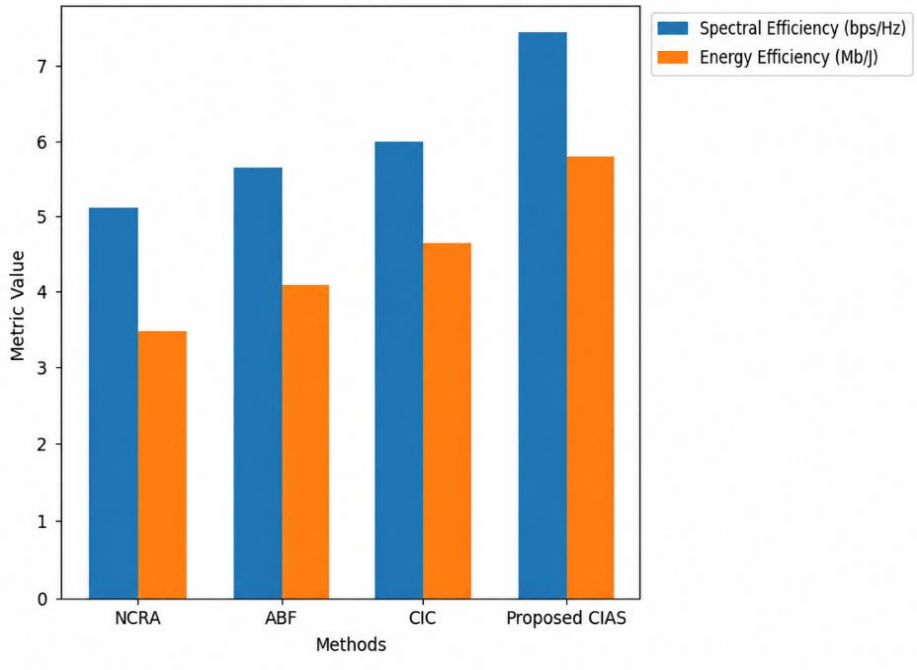


Figure 5: Spectral and energy efficiency comparison of evaluated schemes

Figure 5 summarizes the spectral efficiency and energy efficiency comparisons of the analyzed schemes under the heterogeneous WiMAX-LTE coexistence environments. The proposed CIAS scheme performed best in both terms, which indicates that the CIAS scheme can improve the utilization of available spectrum resources as well as save energy when transmitting data over the air.

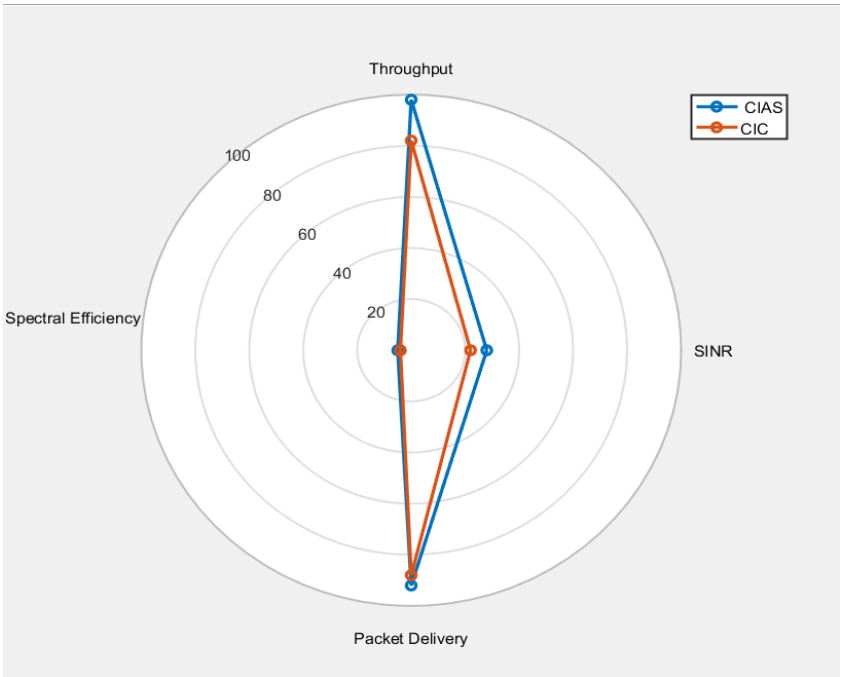


Figure 6: Multi-Metric performance comparison of CIAS and CIC

Figure 6 displays a radar chart which represents comparison among the analyzed schemes under five evaluation metrics including throughput, SINR, packet delivery ratio and spectral efficiency between the proposed CIAS scheme and benchmark CIC method. It is quite evident that the area of the radar chart by CIAS scheme covers the area covered by the CIC scheme; thus, CIAS scheme is superior than the CIC scheme.

The performance gains due to CSI cooperation, alignment optimization, and coordinated scheduling are clearly demonstrated by the ablation results. The overall throughput and SINR of the final combined CS1A system show that the optimal combination of all the three cooperative schemes provides the highest rate.

5 Discussion

The obtained results suggest that cooperative interference alignment presents a viable means of enhance co-existence performance in heterogeneous WiMAX-LTE environment. By establishing an exchange of channel information between nodes of the different type in a coordinated manner, the interfering signals can be contained within the desired subspaces, releasing the portion of bandwidth available for transmitting signal. Through this cooperative means, a efficient use of resources and the gains of 96.8 Mbps and 7.42 bps/Hz in terms of throughout and spectral efficiency may be obtained, respectively, while improving interference management the SINR is boosted to 24.6 dB in scenario and dependability through reduced outages probability of 3.8% and packet delivery ratio of 97.9% allows stable service. From the user-experience point of view, the retransmissions are minimized, fluctuations are smooth and service is always there, although additional overhead is added to coordinate operation including exchanges signalling overhead, generation and updating of the alignment matrices, and channel estimation of different systems. The study also hints that the presented system remains efficient as the number of nodes are further increased but the frequency of coordination is balanced with the benefits derived from it. This system therefore may well become part of the solution for the co-existence of heterogeneous networks in terms of performance and dependability and spectral efficiency in the future.

6 Conclusion

The Cooperative Interference Alignment Scheme (CIAS) for WiMAX-LTE heterogeneous coexistence environment was proposed in this paper with the goal of reducing interference, increasing spectrum efficiency and enhancing the communication reliability. By integrating cooperative channel state information sharing, adaptive alignment matrix generation and coordinated transmission scheduling, the presented system can cope with cross-technology interference better than traditional schemes. Simulation results illustrated the good performance of the presented algorithm from several perspectives. Throughput of 96.8 Mbps outperformed other traditional schemes like interference coordination and adaptive beamforming techniques. Spectral efficiency obtained was 7.42 bps/Hz. The proposed system could improve the average SINR to 24.6 dB and decrease outage probability to 3.8%. Besides, the packet delivery performance improved to 97.9%. Theoretical implication: this work extended the notion of interference alignment to WiMAX-LTE heterogeneous coexistence scenarios and introduced a cooperative alignment which is capable of managing interference between different radio access technologies. Practical implication: the proposed framework can provide an effective solution for spectrum sharing that supports multi-standard wireless systems. The proposed solution is able to improve network efficiency without using more spectrum. Future works: future directions for this work may include the application of the proposed framework in 5G and 6G networks, the use of machine learning-based interference prediction, the incorporation of intelligent spectrum management, and adaptation for ultra-dense heterogeneous networks.

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