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Power Adaptive Cognitive Pilot Channel for Spectrum Co-existence in Wireless Networks

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Abstract— **Next generation wireless networks will be heterogeneous, where several primary users (PU e.g. licensed users) and secondary users (SU e.g. unlicensed users) can operate in the same dynamic and reconfigurable networks at a given time. The major challenge in this heterogeneous radio environment is to enable the coexistence between PU and SU which will further improve the efficient use of radio spectrum. Most of the existing coexistence techniques encounter with challenges due to lack of a priori knowledge about the primary system. Therefore Cognitive pilot channel (CPC) is a proposed approach which could enhance the coexistence by conveying some priori information. However, to achieve a peaceful coexistence it is essential to adopt a mitigation technique according to the CPC information. There is no algorithm has been described so far to integrate the CPC information with existing mitigation technique. In this paper, we proposed a novel power adaptation and integrated zone model (PAIZM) CPC algorithm for peaceful coexistence in heterogeneous networks. Moreover we have implemented and evaluated the PAIZM-CPC model as a coexistence enabler. The results show an enhancement compared with the existing coexistence techniques**.

Keywords-Reconfigurable networks; mitigation techniques; co-existence; cognitive pilot channel; spectrum sharing

I. INTRODUCTION

Existing radio spectrum allocation's policies for several communication applications are indeed inflexible due to the fact that most of the radio spectrum is usually allocated to specific users called PU. However, with most of the spectrum being already allocated, it is becoming exceedingly hard to find unoccupied bands to either deploy new services or to enhance the existing one due to the lack of frequency bands in radio spectrum. Therefore, the point of coexistence issues arises when different systems share the same set of frequency bands in a certain geographical region. The report ETSI 102 754 V 1.1.1 (2008-04) [1] and wisair in [2] defines "detect and avoid" (DAA) based interference mitigation architecture for UWB (SU) device to protect BWA (PU) systems. Moreover in order to define the proper isolation distance it is required to characterize the local observation with a known and specified set of parameters. In [3], UWB interference mitigation technique is proposed for improving coexistence with UMTS or WIMAX terminals in non-cooperative scenario by changing its transmission parameters, such as power and bit rate. The coexistence problem between multiple UWB devices and UMTS has been discussed in [4] and shows that conflict free coexistence is possible when a moderate number (less than 24) of simultaneously active UMTS terminals and UWB devices operate in close vicinity of the UMTS receiver. Cooperative detection/sensing is proposed in [5] which can be implemented either in a centralized or in a distributed manner. Spectrum coexistence of IEEE 802.11b and 802.16a network has been studied using common spectrum coordination channel (CSCC) to enable spectrum coordination policies and reduce the interference [6]. The goal of dynamic spectrum allocation protocol (DSAP) is to increase performance of wireless networks by intelligently distributing segments of available radio frequency spectrum to wireless terminals to avoid congestion, minimize interference, and to adjust the clients' wireless medium usage to fit the network administrator's needs [7].Although the interference mainly takes place at the receiver side, most of the aforementioned proposals are mainly focused on coexistence in transmitter-centric way. Another drawback of existing coexistence techniques is that it is required to scan the full spectrum which is most time and power consuming and also not reliable in case of low data traffic. In order to accelerate the coexistence techniques, it is necessary to have some priori information about the radio environment. Therefore, the CPC concept is analyzed with the aim to convey the necessary information, which will let the cognitive terminal know the spectrum allocation aspects, as well as radio channel access parameters. Since devices which employ different radio access technology (RAT) cannot communicate, the main assumption of the approach is that most of systems causing coexistence issues can be reached via indirect communication. In order to that, it is necessary to have an algorithm or operational framework which describes the procedure to exchange radio spectrum parameter between SUs as well as PUs. Moreover, any real time network scenario has not been considered so far to

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implement CPC as a coexistence enabler in the current literature. In this concern we have proposed the novel PAIZM-CPC implementation as well as its operational framework to counteract the existing bottleneck of CPC implementation for peaceful coexistence.

The remainder of this paper is organized as follows; section II briefly studies the concept of CPC. The novel concept of PAIZM-CPC implementation is presented in section III. PAIZM CPC operational framework and algorithm flow diagram are described in section IV. The PAIZM CPC information elements are described in section V. Section VI explains how enhancement can be achieved with the aid of PAIZM-CPC (Data) aided coexistence techniques. The simulation results of proposed PAIZM-CPC algorithm are presented in section VII and finally conclusions are drawn in Section VIII.

II. CONCEPT OF CPC

In [8], CPC was proposed to facilitate the dynamic spectrum allocation strategy by providing the status of radio channel occupancy in certain geographical areas of interest and in the meanwhile it enhanced the RAT selection process. In a dynamic spectrum management context, when a mobile terminal is switched on for the first time, it does not have any knowledge about the existing primary systems or the most appropriate RATs in that geographical location. So it would be necessary to scan the full operational frequency range in order to know the spectrum distribution in certain geographical area, which imposes constraints on consumption of power and time for the end users. In this particular scenario, the CPC can provide the significant information regarding the radio environment in the vicinity of the mobile terminal so that it can start its communication. The basic CPC operational procedure can be structured in two main phases; the first one is the initialization phase or start-up phase and the following one is the updating phase. Fig.1 shows the flow diagram for CPC operational procedure. In the start-up phase, by switching "ON" the radio transceiver the mobile terminal can detect the CPC and optimally determine its geographical location by means of some positioning system (e.g. GPS). The CPC detection will depend on the specific CPC implementation in terms of the physical resources being used. Here we are assuming CPC is operated in a broadcast mode and out-of-band implementation. To get the perfect knowledge of the surrounding radio environment, the terminal extracts the CPC information and can make the decision for initiating its communication. In this phase, the CPC broadcasts relevant information with regard to operators, frequency bands, and RATs in the terminal location. This CPC information is updated in a periodic manner in the updating phase. Due to the mobility of terminals (end users) and dynamic nature of the radio environment, it is necessary to deliver the CPC information with some additional data such as services, load condition etc., in periodic manner to keep track of the most recent spectrum allocation in that geographical region.

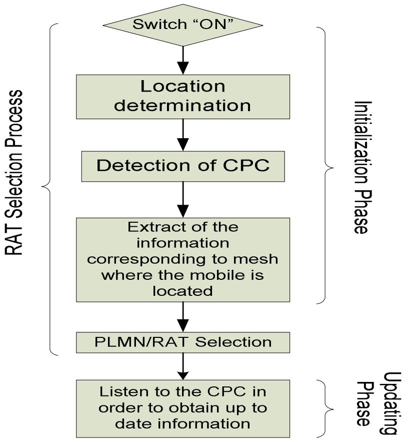

Figure 1. Operational Procedure of CPC

In case of the concept proposed in [8], CPC needs to provide sufficient information to enable effective cognitive processing and cooperation between RATs rather than information allowing initiating an optimal communication session. But the major challenges that restrict us to implement such CPC concept as a coexistence enabler are as follows:

1. CPC is a centralized approach
2. The initial approach of CPC does not consider how to exchange information between PUs and SUs
3. The initial approach of CPC is only provide enhancement for interference detection but does not consider the interference mitigation.
4. Moreover, in order to CPC implementation, it does not consider the network architecture. Therefore in the next section we have proposed a novel distributed PAIZM-CPC implementation to deal with the above mentioned challenges and enhance the coexistence of heterogeneous wireless networks.

III. PAIZM-CPC IMPLEMENTATION

Depending on the network architecture, the following section describes different PAIZM-CPC implementation to enhance the coexistence between primary and secondary systems.

A. System Driven PAIZM-CPC Implementation (SD-PAIZM)

CPC can be implemented without any direct coordination from the primary terminals, which is known as System Driven PAIZM CPC (SD-PAIZM CPC) implementation. Fig.2 shows the system originated SD-PAIZM CPC implementation. In this scenario, the CPC manager is responsible to control and manage the CPC, which is connected to the dedicated CPC base station to transmit the CPC information. The CPC man-

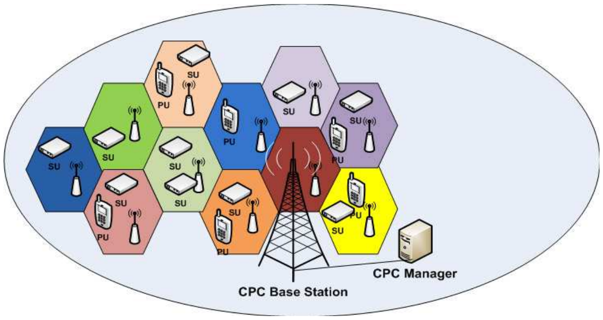

Figure 2. Implementation of PAIZM-CPC without PU Coordinator

-ger may obtain the information over the out-band CPC via joint radio resource management (JRRM) or other functions on network side. In this scenario, CPC can seen as a mechanism used to broadcast the PU physical parameters so that the SUs or any other users can use them and apply precise mitigation techniques based on the detection knowledge about primary systems.

B. *Terminal Driven PAIZM CPC Implementation (TD-PAIZM)*

The underlying concept of this method is to transmit the CPC information by primary receiver (by using CPC RAT) so that it is possible to eliminate the need of sensing and directly exchange the information between the PUs and the SUs to assist coexistence. This is known as terminal driven PAIZM-CPC. In this architecture, it is assumed that the PU is a dual radio device; the extra radio is used to transmit CPC information. TD-PAIZM CPC information is transmitted in on-demand basis. Therefore, the primary receivers monitor its QoS in terms of BER, SNR or PER, if it drops under certain threshold, it will trigger the CPC transmission. Fig.3 shows the TD-PAIZM CPC implementations without any secondary central coordinator. In this scenario the CPC will broadcast directly to each terminal in the secondary networks to make it aware about possible interference issues. Therefore all the SUs can perform some sort of measurement of QoS (e.g. SNR) on the CPC frequency and can easily adapt the DAA Zone Model [1] or other mitigation technique. On the other hand; Fig. 4 shows the implementation scenario between the PU and the SU which are coexisting with a central coordinator. According to the structure, it will transmit CPC information towards the gateway terminal or the central terminal instead of individual SUs. Afterwards the central terminal will retransmit the In-band CPC information to all the RATs and therefore the proper reaction of the SUs on the received CPC information can be achieved.

C. *Hybrid PAIZM CPC Implementation (HY-PAIZM)*

In order to address the problem of congestion on CPC channel caused by high user density in the area, different primary systems could be assigned with different terminal originated CPC channels. In this context, the best solution is to combine SD-PAIZM-CPC and TD-PAIZM CPC, where SD-PAIZM CPC is responsible for conveying information about allocation of TD-PAIZM CPC channels. Moreover, SD-PAIZM-CPC will convey the information of PUs which are not capable to originate CPC information. TD-PAIZM CPC will operate as discussed before. Fig. 5 shows the HY-PAIZM CPC implementation scenario.

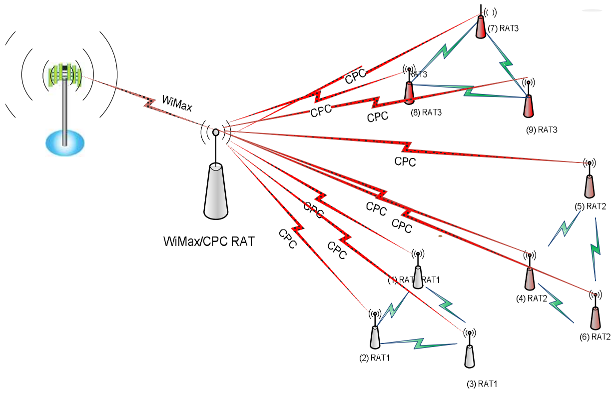

Figure 3. Terminal Driven CPC Implementation Scenario without Central Coordinator

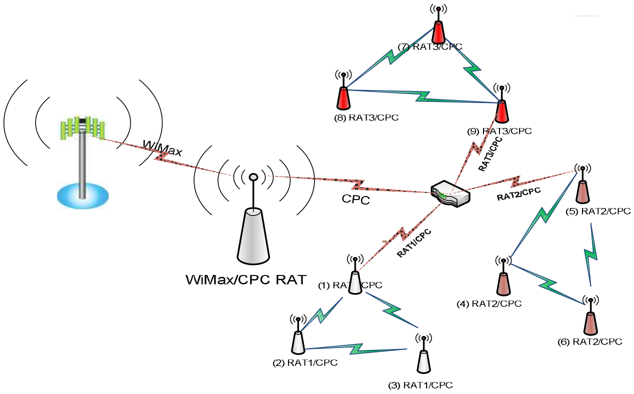

Figure 4. Terminal Driven CPC Implementation Scenario with Central Coordinator

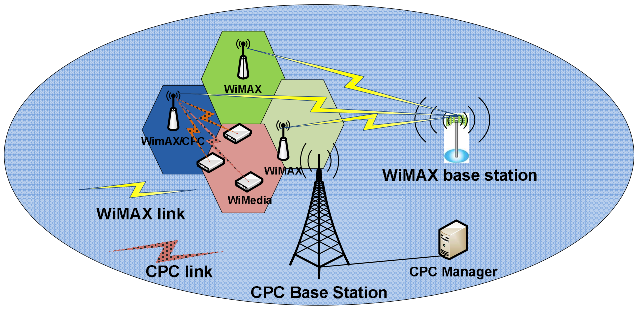

Figure 5. Illustration of HY-PAIZM CPC Implementation

IV. PAIZM CPC OPERATINAL FRAMEWORK

In this section, the operational framework of PAIZM CPC is presented. Depending on the different network architecture, the implementation of PAIZM-CPC and their corresponding operational framework can be distinguished. Fig.6 shows the operational framework of PAIZM-CPC for different implementation scenario which are described in previous section.

- In SD-PAIZM CPC, part 2 and part 5 are mainly active to enable the coexistence technique. Whenever an SU turns on its radio transceiver, it will first listen for PAIZM-CPC and then identify the source of CPC generation. Since SD-PAIZM CPC will only provide the indication of the presence of the primary system, there is still the need to scan the primary systems operating band in a periodic manner. On the basis of the SD-PAIZM CPC, the SUs conduct scanning on the PUs operating frequency and employ an accurate mitigation technique to avoid possible interference which is shown in part 5.
- In TD-PAIZM CPC, part 1, part 2 and part 4 will perform the whole operation to establish the peaceful coexistence. Since interference actually takes place at the receiver side, enhancement of the coexistence techniques will be significant if there is a priori knowledge of the primary receiver. In this framework, deployment of Part 1 is mainly aimed to provide CPC information and notice the possible interference issues by the PU itself and trigger the TD-PAIZM-CPC transmission. Like the previous case, part 2 will distinguish the source of CPC generation. Part 4 is responsible for enhancing the DAA zone model with by using TD-PAIZM-CPC information. After receiving the TD-PAIZM-CPC information, the SU will measure the SNR on the TD-PAIZM-CPC channel so that it evaluate whether the possible interference is due to its transmission or not. If so, an SU will calculate the proper radio isolation between the PU and the S and eventually control the transmission power.
- In HY-PAIZM CPC, all of the part of operation framework will deployed. Depending on the information received form part 2, the secondary system will identify the number of TD-PAIZM-CPC capable primary system and ordinary primary systems (not capable to transmit TD-PAIZM-CPC). If there is more than one TD-PAIZM CPC capable PU, it is required to identify the PAIZM-CPC frequency channels for each primary system. In this context SD-PAIZM-CPC will provide the frequency allocation for TD-PAIZM-CPC. This task is carried out by part 3. After wards, the above mentioned information will use to adopt an exact mitigation technique. In that case if it is SD-PAIZM-CPC it will go for part 5 otherwise part 4 will follow for the rest of operation.

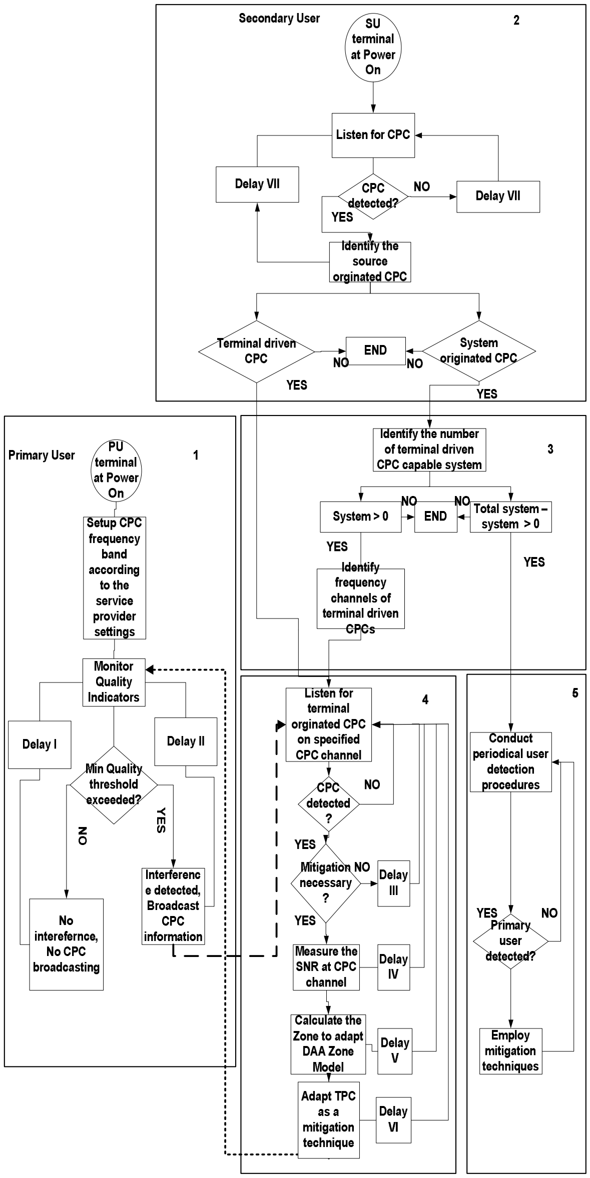

Figure 6. Operational Flow Diagram for PAIZM-CPC Implementation

V. PAIZM CPC INFORMATION ELEMENTS

Depending on the implementation, CPC may carry different sets of information [8]. Since the initial concept of CPC was focused on the process of assisting a terminal in a RAT selection process, limited data has been advised to be advertised via CPC (e.g. operator, RAT type, frequency allocation). In [10] it has been evaluated the required bit rates for broadcast CPC implementation.. For practical deployments where 5 operators are available, each with different RATs, each RAT with 10 advertised frequencies:

- N_{OP} = 5; Number of Operators.
- N_{RAT} = 5; Number of RATs.
- N_{FREQ} = 10; Number of advertised frequencies of each RAT.
- B_{OP} (Operator Information) = 20 bits; for each operator, the identifier can be mobile country code and mobile network code, consisting of 3 and 2 digits respectively.
- B_{RAT} (RAT Information) = 4 bits; 15 different RATs and one reserved for the secondary use (e.g., 1111).
- B_{COV} (Coverage Information) = 1 bit (1 for Global and 0 for local)
- B_{GEO} (Geographical Coordinates) = 41 bits;
- B_{RADIUS} (Dimension of mesh) = 12 bits (Coverage area)
- B_{FREQ} (Frequency Information):16 bits (Frequencies ranges from 0 to 10GHz with a raster of 200 KHz)

In simple equation the total number of bits can be calculated as [11]

$$\begin{aligned} B_{TOT} &= N_{OP} \times (B_{OP} + (N_{RAT} \times (B_{RAT} + B_{COV} + B_{GEO} + \\ &\quad (B_{RADIUAS} + (N_{FREQ} \times B_{FREQ}))))) \\ &= 5 \times (20 \ + (5 \times (4+1+41+(12+(10 \times 6 \ ))))) \\ &= 5550\, Bits \end{aligned}$$

But this information is only to assist the RAT selection process. In order to facilitate the coexistence issue the change in the scope of CPC introduces the need to extend the amount of information conveyed by the channel. This may raise a demand to increase the bandwidth. The information that has to consider for enabling the coexistence is: duplex system information, maximum tolerable interference level, source of CPC information. Duplex system information will assist the secondary user to adopt an appropriate mitigation technique for a particular frequency band. In case of primary FDD system it is necessary to apply a mitigation technique only for downlink channel but for TDD mode it should consider for the whole TDD frequency band of a particular primary system. We are using maximum tolerable interference level of the primary system for calculating the protective isolation distance between the primary and secondary system in DAA method. The source of CPC information is obvious in knows system and terminal level information of the primary user.

- B_{DUPLEX} (Duplex Information) = 5 bits; (if all zeros then TDD otherwise it is FDD)
- $B_{MAX\_INTERFERECE}$ (Maximum Tolerable Interference Level) = 8 bits;
- B_{S_CPC} (Source of CPC information) = 1 bit (1 for system level and 0 for terminal level)

$$\begin{aligned} B_{TOT} &= N_{OP} \times (B_{OP} + (N_{RAT} \times (B_{RAT} + B_{COV} + B_{GEO} + \\ &\quad + B_{DUPLEX} + B_{MAX\_INTRERFERENCE} + (B_{RADIUAS} \\ &\quad + (N_{FREQ} \times B_{FREQ}))))) + B_{S\_CPC} \\ &= 5 \times (20 \ + (5 \times (4+1+41+5+8+(12+(10 \times 6)))) + 1 \\ &= 5875\, Bits \end{aligned}$$

Assuming that each user should be able to gain knowledge of broadcast information in maximum $T_{DELAY} = 0.5 \sec onds$ [11], the net bit rate that should be available to the CPC is

$$R_B = \frac{B_{TOT}}{T_{DELAY}} = \frac{5875}{0.5} = 11.75 \ kbps$$

The information carried by the channel can be subdivided into three groups: static, slowly varying and dynamic. As the name suggests, the first group of information does not change with time and usually carries information such as: Operator, Type of RAT, Duplex information. The second group usually carries information regarding the frequency allocation which may slowly vary due to the DSA/FSM mechanism. The last group of parameters targets temporary system states. In the near future traversing those parameters may open a wide spectrum of different possibilities to exploit instantaneous system states in order to improve the coexistence between different technologies. This could be especially helpful in the process of inter-RAT Secondary User coordination (IEEE 802.15.4a, WiMedia).

VI. IMPROVEMENT OF EXISTING CO-EXISTENCE TECHNIQUES

Our proposed PAIZM-CPC technique preserves the DAA mechanism introduced in [1] and shows that performance gain can be achieved by providing additional, accurate and reliable set of radio information. These set of information are further use to improve the process of detection and mitigation.

A. Scanning Improvment

The improvement introduced by PAIZM CPC-aided approach would be to scan only bands advertised by CPC as occupied and thus significantly decrease the time which needs to be spent in the process of the PU detection. Also it can decrease the probability of appearing any coexistence due to the possible miss detection caused by fast scanning process. According to the Intel proposal [9], scanning in WiMedia has to be conducted separately for each sub-band. This means that a WiMedia device employing a 3 sub-band hopping pattern would need to spend a significant amount of time in the process of fine scanning. In case of PAIZM CPC existence, this time would be significantly decreased.

B. Signal Detection Improvement

Having accurate information about the frequency allocation of existing primary system in a given area, PAIZM CPC-aided devices could detect PU in a more effective way by discarding all the irrelevant information gathered in the process of scanning spectrum. What is more, the exact knowledge of the primary systems signal parameters could be used to introduce coherent sensing techniques thus introducing significant improvements in terms of minimal SNR allowing detection of the PU signal.

C. Cell Edge Scenario Issue

The problem of the "listen before send" devices e.g. WiMAX terminal with Base Station cannot be solved by PAIZM CPC straight forwardly. An improved version of "roll notch" technique could be implemented in this case for WiMedia device [12]. The already mentioned problems of the resource wastage and lack of information about duplex separation can be easily solved by extracting them from PAIZM CPC. Having the knowledge about the existence of WiMAX service in a given area and specific frequency allocation of a downlink channel would result in significant improvement of the solution. The obvious improvement introduced by the CPC approach is to employ the "roll notch" technique only in the presence of a WiMAX service. Moreover, in case of having full knowledge about the WiMAX service frequency allocation, the "roll notch" could be simply degraded to a periodical, fixed notch. The improvement for the "roll notch" technique could be especially visible when a 3 band hopping pattern is employed by MB-OFDM device. Figure 7 shows the operational procedure of rolling notch technique for both PAIZM CPCs aided and non-CPC aided mitigation technique. In the bottom part of the fig.8 a non-CPC aided scenario is described where all the bands need to be swept which decrease the performance in terms of required SNR to maintain BER equally on every band. In case of PAIZM CPC-aided approach shows in the fig.8 the tone notch is only used periodically in one sub-band, thus allowing transmission on other sub-bands to be unaffected. While providing the same reliability, the PAIZM CPC aided technique could then decrease the time when the "roll notch" needs to be applied and thus significantly improve MB-OFDM device performance. An alternative to the mentioned approach would be simply to use a static notch (blind technique). However, as mentioned before, the performance of the technique could vary on a scenario to scenario basis (static application of a notch could decrease the achievable bit rate).

D. Enhancement of DAA proposal

Earlier DAA proposals severely suffer from inaccurate estimation of radio isolation between PU and SU in case of power control mitigation technique. Fig.8 shows the enhancement that can be achieved if we have PU information by means of CPC. In TD-PAIZM CPC implementation, PAIZM CPC is transmitted by the PUs, so that the SUs can easily determine the operating zone in DAA by measure the power level on the CPC channel.

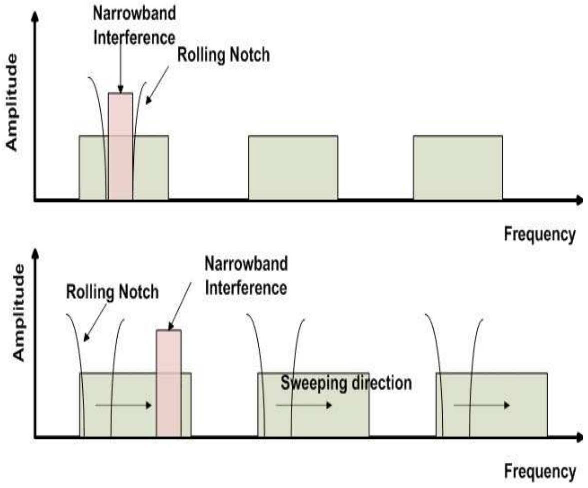

Figure 7. PAIZM CPC-aided (top) and Non CPC-Aided (bottom) "Roll Notch" Technique for 3 Sub-Band Hopping Pattern

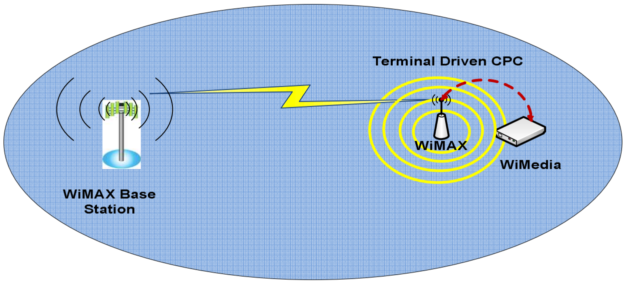

Figure 8. Enhancement of DAA Proposal

VII. SIMULATION AND RESULTS

Simulations are performed using the Optimized Network Engineering Tools NS2-Multi Interface Cross Layer Extension (NS2-MIRACLE) simulator. The earlier version of NS2 (network simulator 2) does not support multiple radio interfaces and lacks flexible tools for the cross-layer control of communication systems In order to observe the performance of different coexistencetechniques, we have conduct mainly two simulation measurement; one is for analyzing the detection delay performance and another one for throughput analysis.

A. Detection Delay Measurement

Detection delay is the time required by the SUs to detect the PUs in its vicinity. Fig.10 shows the performance of CBR and HTTP traffic detection for different coexistence techniques. Due to the sparse nature of HTTP traffic the detection delay is higher than the CBR traffic for both DAA and Cooperative-DAA. In case of DAA, each node has its own detection parameter and based on this information decision is made. Therefore there is no significant change in the performance if we increase the number of SU and it is remain constant in 121ms and 59ms for HTTP and CBR traffic respectively. On the other hand in Cooperative DAA, each node shares its local observation and the decision is made in collective manner. As a consequence the detection delay is decreases with the increase of number of nodes. In this case detection delay is dramatically fall from 121ms to 38 for HTTP traffic and form 59 ms to 10ms for CBR traffic. In case of PAIZM CPC, the detection delay is no longer depends on SU but on PU. In case of PAIZM CPC implementation the CPC is transmitted when there is an issue of interference realized by PU. In our simulation, we found that CPC information is transmitted at 2 seconds with single SU and depending upon this all the SUs easily perform the scanning only the particular frequency. We also found that if we increase the number of nodes CPC is transmitted momentarily. But in order to realize CPC functionality we restrict it in 2ms.

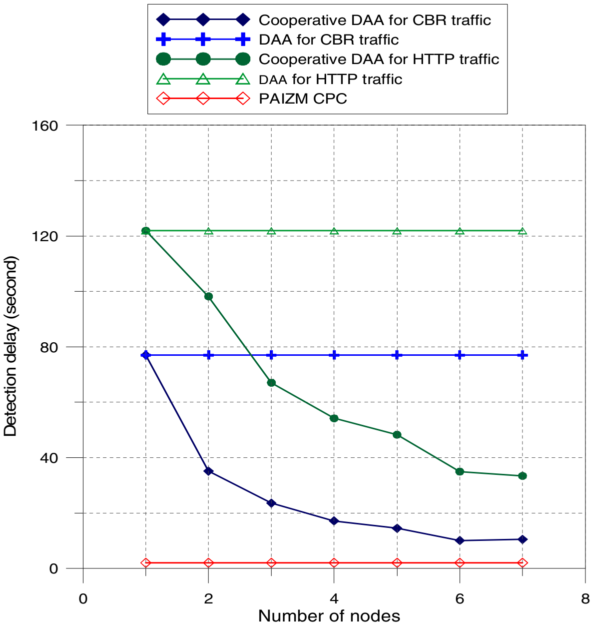

Figure 9. Performance of PAIZM CPC implementation

A. Throughput Loss Measurement

In order to compare the WiMAX throughput, we first conduct the simulation without taking consideration of any SUs in the vicinity. We also observe the performance of WiMAX in the presence of the SUs with adopting different coexistence techniques. Fig.11, describe the throughput loss in percentage of WiMAX transmission. Due to the presence of noise and some other interference there is inevitable throughput loss when there is no SU transmission which is about 1.8 percent. But the throughput loss is increased by 15 percent when we turn on the SU transmission. We have seen that throughput loss is significantly reduced by 37.5 percent by adopting DAA coexistence technique. There is a dramatic improvement can be achieved with cooperative-DAA. The performance of the PU is improved dramatically by using interference based TD-PAIZM CPC information. In case of TD-PAIZM CPC coexistence technique the performance increased by 95 percent. The same simulation has been conducted also to observe the throughput loss in case downlink transmission of WiMAX, since interference is mainly takes place at the receiver side.

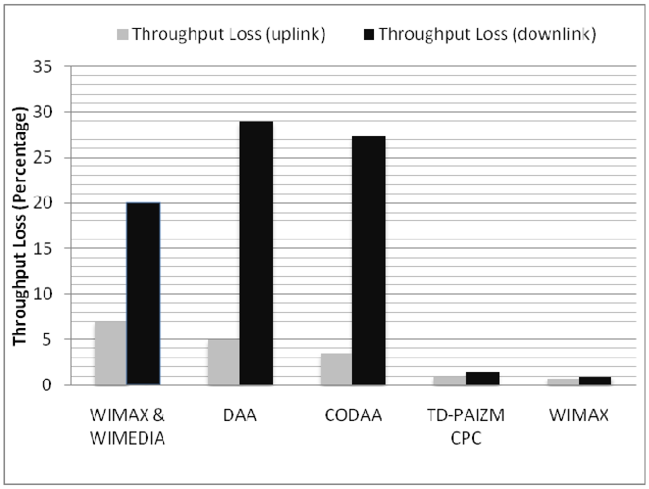

Figure 10. Performance of WiMAX Transmission with Different Coexistence Techniques

VIII. CONCLUSION

The pinpoint of the paper is to develop a spectrum coexistence operational framework by integrating the CPC information with existing mitigation techniques. In this context, our research brought out a novel concept of PAIZM-CPC implementation. To gain insight of different design options, we introduced SD-PAIZM, TD-PAIZM and HY-PAIZM CPC implementation scenario. We have also presented an operational framework to design power efficient CPC algorithm and interface with existing mitigation techniques. Eventually a comparison has drawn with existing coexistence techniques through simulation. It is apparent from the simulation results that PAIZM-CPC can enhance the performance of coexistence between PUs and SUs.

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