Code Sectoring Methods in CDMA-Based Broadband Point-to-Multipoint Networks

Csaba Novák, András Tikk, and János Bitó

***Abstract*—Code sectoring methods in broadband wireless point-to-multipoint (PMP) networks applying code-division multiple access (CDMA) are discussed in this paper. Interference reduction is the key factor in PMP network design, therefore antenna- and frequency-sectoring solutions are commonly applied. CDMA allows code sectoring strategies, moreover advanced interference suppression techniques (e.g., multiuser detection) can be utilized. The combination of different sectoring schemes and multiuser receivers in a CDMA-based PMP network provides the effective control of interference. In this study different CDMA code sectoring approaches are proposed and downlink interference analyses of a PMP network sector are presented.**

***Index Terms*—Broadband fixed wireless access, code-division multiple access, multiuser detection, parallel interference cancellation.**

I. Introduction

BROADBAND fixed wireless access (BFWA) is an emerging technology offering cheap alternative to copper- and fiber based solutions. The bottleneck of point-to-multipoint (PMP) networks is interference. To maintain acceptable interference level sectored antennas on the base stations (BS) and narrow-beam terminal station (TS) antennas focused on the serving BS are practically used. Frequency reuse is also preferred according to the cellular principle. Such configuration is illustrated in Fig. 1(a), showing a network comprising 3×3 BSs arranged in a rectangular grid with typical 90° sectored antennas and the most common sectoring approach with four frequencies (marked with different tones). Critical downlink interference situations are depicted by arrows. The denoted TS of the bottom left sector receives interference from sectors operating at the same frequency and transmitting to the same direction. The corresponding C/I map is shown in Fig. 1(b), calculated with antenna patterns of ETSI recommendations for broadband PMP systems [1]. Critical positions with poor C/I values occur along the sector borders and diagonal.

Code-division multiple access (CDMA) provides robust air interface for PMP networks by its interference suppression capability, as examined in [2]. The present work exploits interference controlling capabilities of CDMA by proposing advanced code utilization schemes together with location dependent receiver algorithm, which results a subsectoring scenario. In future BFWA systems asymmetric applications

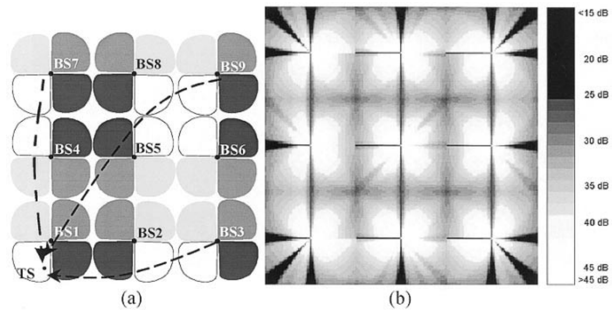

Fig. 1. (a) Downlink interference situations and (b) corresponding C/I map of four-frequency PMP network with 3×3 BSs.

are foreseen, therefore we restricted ourselves to downlink interference investigations. Simulation results are given for a CDMA-based PMP network sector, including bit error rate (BER) maps and BER versus signal to noise ratio (SNR) analyses.

II. Applying CDMA in PMP Networks

Because line-of-sight connection is a requirement in BFWA systems, applying millimeter-wave frequencies, e.g., 40 GHz, fading due to meteorological phenomena i.e., rain attenuation is the dominant degradation factor rather than multipath fading. Multipath fading mitigating effect of CDMA, therefore, cannot be exploited, applying CDMA has not yet been preferred in BFWA, however recent studies [3] have shown that CDMA can compete with the most common time-division multiple access (TDMA). Whereas TDMA requires accurate time-frame synchronization, this can be ignored in CDMA assuming a code set with advantageous cross-correlation properties, however, multiple access interference (MAI) will increase the noise floor [4]. Furthermore, CDMA provides inter-system interference suppression determined by the processing gain. Applying CDMA the whole available frequency band can be utilized, frequency sectoring can be avoided.

Without frequency sectoring, interference is received from all sectors looking to the same direction – compared to the four-frequency sectored case in Fig. 1. The origin of interfering signals can be revealed by examining the most interfering sectors in each position. This way the investigated sector can be divided into subsectors comprising separate zones, which have common main interferers. Fig. 2 shows five interference zones of the examined corner sector of the network. In Fig. 2(a)–(e) the dominant interferers are depicted for the five zones respectively. Sectors in these maps marked with darker tones indicate higher interference level received from the certain sector.

Manuscript received February 4, 2003; revised March 21, 2003. The review of this letter was arranged by Guest Editor Roberto Sorrentino.

The authors are with the Department of Broadband Infocommunications and Electromagnetic Theory, Budapest University of Technology and Economics, H1111 Budapest, Hungary.

Digital Object Identifier 10.1109/LMWC.2003.815703

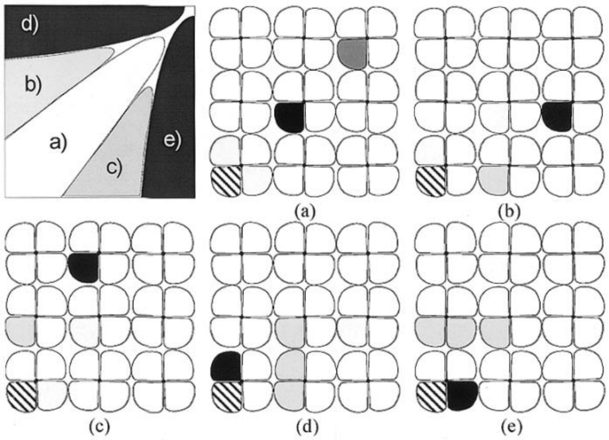

Fig. 2. Subsector allocation of the bottom left sector (hatched sector) of a single-frequency CDMA-based PMP network; constructed from interference zones (zone "a" – zone "e"). The corresponding 3×3 network maps (a-e) mark the most dominant interferer sectors with decreasing grey levels for each zone, respectively.

A. CDMA Multiuser Detection

The application of CDMA produces inter-sector interference which is the multiple access interference (MAI) caused by nonorthogonal pseudo noise (PN) codes assigned to the sectors. Multiuser detection aims to remove MAI when detecting the desired user. In our contribution parallel interference cancellation (PIC) detector is investigated. Assuming a CDMA system with K users transmitting continuously the received signal is given by (1)

$$r(t) = \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} A_k b_k(i) s_k(t - iT - \tau_k) + n(t) \quad (1)$$

where the k^{th} user is identified by spreading waveform s_k, $b_k(i)$ denotes the sent i^{th} bit with the duration T, A_k is the received amplitude of the k^{th} user and n is the white Gaussian noise. The PIC receiver [4] detects all users at the same time with a first bank of matched filters (MF). The output vector of the first MF bank $\hat{\mathbf{b}}^{(0)}$ is used for respreading and subtracting from the delayed received signal, which then will be the input of a second MF bank to perform the final decision corresponding to (see (2) at the bottom of the page).

B. Code Utilization – Code Sectoring

Four code sectoring strategies are introduced: *Code I* and *II* for single-frequency, and *Code III* and *IV* for four-frequency approaches.

1) Code I: A unique identifying code is assigned to each sector. Because of different delays of the received signal components from different sectors, PN codes should be used, which provide acceptable cross correlation properties. Sector synchronization therefore can be avoided. Users of a certain sector are separated by orthogonal Walsh codes. A certain TS receives the desired signal spread by the PN code identifying its serving sector and also multiplied by its unique Walsh code, identifying the desired downlink connection, similarly as in UMTS [5]. As on the downlink the BS separates the users' signals by orthogonal Walsh-codes, intra-sector interference at the TS does not occur. Because the sector identifier PN codes are not orthogonal, inter-sector and inter-cell interference must be taken into account.

2) Code II: If the four sectors belonging to one BS are synchronized, orthogonal Walsh codes can separate all subscribers of the cell coverage area. One PN code is assigned to each cell. Four orthogonal Walsh code sets are assigned to the four sectors of a cell, eliminating intra-cell interference.

3) Code III: Reduced inter-sector interference by the four-frequency sectoring allows simpler code utilization, exploiting the possibility of code sectoring is not necessary. In this approach, the same PN code set is applied in all of the sectors.

4) Code IV: Unique PN codes are assigned to each cell, bit-asynchronism between the sectors is allowed in contradiction to the similar single frequency code system II. Code system IV is also the combination of PN + Walsh codes, similarly as code systems I and II. The same Walsh code set is utilized in each sector for TS separation.

C. Location-Dependent Receiver Subsectoring With Multiuser Detection

The PIC receiver assumes the knowledge of all spreading codes used in the interference canceling algorithm as given in (2). In PMP systems this would lead to very complex receiver structure, whereas in practical signal processing units a limited number of matched filters are available. As it could be seen in Fig. 2, in most of the TS positions only a few sectors cause most of the interference. Receiver complexity can be reduced by assigning only a few branches of correlators to the most dominant interferers, without the significant decrease of interference suppression efficiency, as examined in our former study [6]. This optimum allocation of signal processing capacity means a location dependent receiver algorithm. Interference zones of a sector will lead to subsectors in terms of multiuser detection algorithm, this way a further sectoring procedure is obtained.

III. Simulation Results

Our simulations compare different sectoring methods in CMDA-based PMP networks. Free-space line of sight propagation conditions were assumed in the 26 GHz domain taking signal attenuation proportional to the square of the distance. All BSs transmit with the same power. ETSI-recommended [1] BS and TS antennas were applied. Considering CDMA codes, PN codes of code system I and II are 64 chip long Gold codes. Users of a certain sector are separated by orthogonal 64 chip

$$\hat{b}_k(i) = \operatorname{sgn}\left[\int_T \left(r(t) - \sum_{j=1, j\neq k}^{K} A_j s_j(t - iT - \tau_j)\, \hat{b}_j^{(0)}(i)\right) s_k(t - \tau_k)\, dt\right] \quad (2)$$

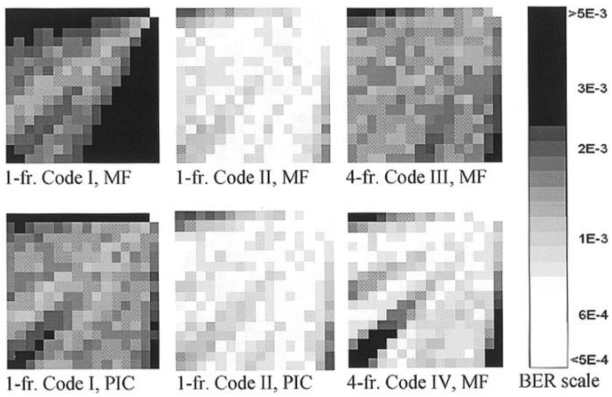

Fig. 3. Downlink BER conditions of the examined CDMA-based PMP network sector applying single-frequency and 4-frequency approaches, code sectoring schemes I-IV, MF and PIC receivers, $\mathrm{SNR} = 7\ \mathrm{dB}$.

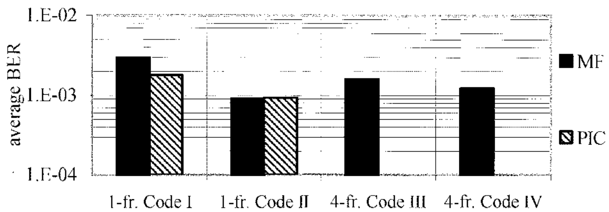

Fig. 4. Sector average BER values for the corresponding maps of Fig. 3.

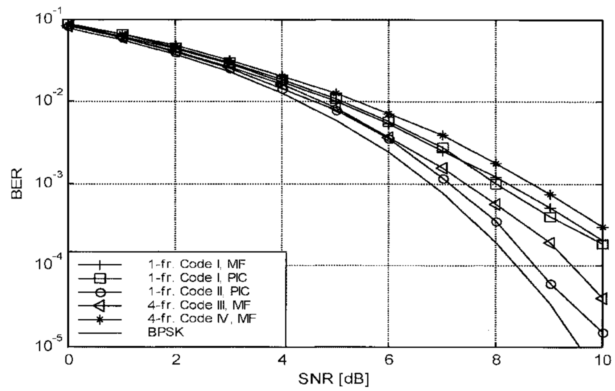

Fig. 5. Downlink BER versus SNR analysis at a fixed location of CDMA-based PMP network applying different frequency- and code sectoring schemes with MF and PIC receivers.

long Walsh codes, as described in Section II. In four-frequency sectored approaches to preserve signal bandwidth, code length divided by four was applied in code systems III and IV. PIC receivers were applied in code systems I and II, with reduced complexity having matched filter banks for the five most interfering sectors as introduced in Section II.

Maps of Fig. 3 indicate BER conditions of the examined bottom left sector. A tone of a certain point on the map indicates the BER value on the downlink of a hypothetical TS installed at that point. The dark first map of Fig. 3 (1-fr. Code I, MF) indicates poor BER conditions due to heavy interference, especially at the border positions. In this approach nonorthogonal codes are assigned to the asynchronous sectors, therefore adjacent sector interference due to the not perfect side-lobe suppression of BS antennas is critical. Applying location dependent PIC receiver in a subsectoring scenario could significantly improve BER conditions of the border zone (see zones d and e in Fig. 2). Best BER results are shown on light grey maps of code system II. In this single frequency approach effective code sectoring is provided by orthogonal subsets of Walsh codes assigned to synchronized sectors of a cell, however, subsectoring effect of location dependent multiuser detection is not significant. Four-frequency sectored approaches are inferior to Code II scheme. Interference protection by frequency sectoring is not so significant compared to the single-frequency Code I approach, further improving effect of subsectoring by multiuser detection cannot be exploited. Code system III performed nearly the same as Code I with PIC receiver. The map of Code IV indicates significant inhomogeneities in terms of BER having critical diagonal positions with unacceptable BER values. Sector average BER values given in Fig. 4 reveal that PIC detector even worsened the average BER performance of code system II, which is due to wrong initial decisions used in the interference canceling algorithm given in (2). Second best average results are obtained with code system IV, however extreme inhomogeneities observed in Fig. 3 are concealed.

BER versus SNR analyses are shown in Fig. 5, comparing BER performances at the same bottom right point of the examined sector of PMP networks with different sectoring schemes. Four-frequency sectored approach with code system IV performed worse in the selected critical TS location. 1 dB gain at 10^{-3} BER can be achieved by Code I, the best performing Code II with location dependent PIC gains 2 dB at the same BER value.

IV. Conclusions

Sectoring solutions in broadband PMP networks have been examined exploiting code sectoring capabilities of CDMA. Interference analyses of a single-frequency PMP network have shown the existence of interference zones in terms of common dominant interferer sectors of the network. A location dependent interference canceling receiver has been proposed for optimal allocation of signal processing capacity. Applying multiuser detection this way leads to subsectoring according to interference zones, providing further interference suppression capability. BER performance analyses of different sectoring schemes have shown that applying a single-frequency CDMA approach is superior to frequency-sectoring solutions provided by the appropriate code sectoring and subsectoring schemes.

References

[1] “Antennas for Point-to-Multipoint Fixed Radio Systems in the 11 GHz to 60 GHz Band; Part 2: 24 GHz to 30 GHz,” ETSI EN 301 215-2 v1.3.1.

[2] C. Novák *et al.*, “Interference suppression for CDMA-based LMDS networks,” in *Proc. ECWT*, Milan, Italy, 2002.

[3] H. Sari, “A multimode CDMA with reduced intercell interference for broadband wireless networks,” *IEEE J. Select. Areas Commun.*, vol. 19, pp. 1316–1323, July 2001.

[4] S. Verdú, *Multiuser Detection*. Cambridge, U.K.: Cambridge Univ. Press, 1998.

[5] *3GPP Tech. Specification 25.213, Spreading and Modulation (FDD).*

[6] C. Novák *et al.*, “Downlink interference analysis of CDMA-based LMDS networks applying multiuser detection,” in *Proc. EURESCOM Summit 2002*, Heidelberg, Oct. 21–25, 2002, pp. 231–240.