Uplink Interference Analysis of LMDS Networks Applying CDMA with Interference Cancellation

Csaba Novák, Dávid Tóth, and János Bitó

Budapest University of Technology and Economics – Department of Broadband Infocommunications
Goldmann Gy. tér 3., Budapest, H-1111, Hungary, Tel.: +36 1 463-3616, Fax: +36 1 463-3289, e-mails: csaba.novak@mht.bme.hu, dave@mht.bme.hu, bito@mht.bme.hu

Abstract—Local Multipoint Distribution Service (LMDS) is an emerging technology among broadband point-to-multipoint (PMP) wireless networks. The most critical point in designing LMDS networks is interference. Dominant access methods are FDMA and TDMA in LMDS, whereas CDMA received less attention. In this paper our aim is to demonstrate the feasibility of applying CDMA in LMDS networks with exploiting the results of research activities in CDMA interference suppression (e.g. multiuser detection). Uplink direction is the bottleneck of cellular PMP networks in terms of interference. Therefore, we analyzed uplink interference in CDMA-based LMDS networks. Frequency-sectorized TDMA uplink interference scenarios were compared to those of CDMA using single user detector (matched filter) and multiuser detection algorithms i.e. parallel interference cancellation (PIC) and successive interference cancellation (SIC). Uplink investigations of an LMDS sector by carrier to interference ratio (C/I) maps and BER vs. SNR simulations are presented.

I. INTRODUCTION

Local Multipoint Distribution Service (LMDS) is a broadband wireless point-to-multipoint (PMP) communication system that provides two-way high speed multimedia transmission [1]. Increasing demand on wideband applications set wireless fixed networks into focus as a cheap alternative to wired solutions such as digital subscriber line (DSL). LMDS has to fulfill the requirements of copper- and fiber-based networks besides offering high flexibility in network configuration. Considering multiple access schemes for LMDS, mostly TDMA and FDMA approaches were favored. The main advantage of CDMA is the capability of eliminating the influence of frequency selective fading mostly caused by multipath propagation. Because line-of-sight (LOS) connection is a requirement for PMP systems, applying higher frequencies e.g. 40 GHz, fading due to meteorological phenomena i.e. rain attenuation are the dominant degradation factors rather than multipath fading. Therefore, applying CDMA has not yet been preferred in LMDS systems [2]. However, recent studies have shown that CDMA can compete with TDMA [3] and can play a major role in two-layer LMDS architectures [4]. In frequency sectorized LMDS applying TDMA or FDMA, intracell interference is negligible, however, intercell interference can degrade system performance depending on the frequency reuse method. Applying CDMA frequency sectorization can be avoided assuming the existence of satisfactory number of codes. In that case the whole frequency band can be utilized and the interference will be determined by the selected code set. For canceling interference in CDMA systems, multiuser detection (MUD) is the most effective approach, which has been one of the most attractive research topics in CDMA communications for decades [5]. The implementation of MUD, however, has not yet been foreseen in the forthcoming LMDS systems. In this paper we analyse uplink interference in CDMA-based LMDS systems applying MUD at the base stations (BS). Section II gives a brief overview of LMDS, demonstrates interference scenarios in traditional frequency sectorized TDMA approach and with the application of single-frequency CDMA system. In Section III interference suppression with multiuser detection is introduced. In Section IV the results of parallel- and successive interference cancellation are presented by interference maps of a sector together with bit error rate (BER) vs. signal to noise ratio (SNR) simulations at different C/I conditions. In conclusion we summarize the benefits of MUD aided CDMA solution in LMDS systems.

II. LMDS OVERVIEW

LMDS is a cellular networking solution operating at millimeter frequencies, typically in the range of 20-40 GHz (depending on country of licensing). The cell radius is limited to 2-5 km due to propagation conditions. The most common cell sectoring solution uses 90° sectors, therefore BSs can be arranged in a rectangular grid as shown in Fig.1. To reduce intercell interference, terminal antennas use accurate narrow-beam focusing on the selected BS. Primary access methods in LMDS are TDMA, FDMA and CDMA, as mentioned before, the latter gained less attention. Currently, most system operators and standards activities address the TDMA and FDMA approaches. The section hereunder discusses two possible, TDMA and CDMA approaches in terms of interference.
A. Four-frequency sectorized TDMA approach

TDMA assumes time-frame synchronization of the terminal stations (TS), therefore the central controlling of the BSs is necessary. As a large number of TSs has to be served, sectorization is needed. According to the cellular principle, frequency sectoring allows the reuse of spectrum, increasing capacity. Considering the above discussed properties of LMDS, namely 90° sector BS antennas and narrow-beam TS antennas, the following four-frequency sectorized TDMA configuration can be applied as displayed in Fig.1. in case of 3x3 BSs. Four different frequencies represented by different grey levels are used in the sectors of one cell. Fig.1.a) illustrates downlink interference between sectors which transmit to the same direction operating at the same frequency. In that case the denoted TS is disturbed by intercell interference. Similar most disturbing situations occur between all of the second nearest neighbors. Downlink interference situations assuming the same arrangement can be observed in the C/I map of the whole coverage area in Fig.2. calculated with antenna patterns given in Table 1. Critical areas are aligned along the sector borders and in the corners of the 3x3 network. Avoiding critical interfering places play the major role in downlink network planning. Uplink interference situations are illustrated in Fig.1.b). Please observe BS1 in the left bottom corner, which receives interfering signals from the TSs located in other sectors operating at the same frequency and in the same time-slot of the TDMA frame (TS2-TS4). In contradiction to the worst-case downlink situation where TSs at sector borders receive interfering signal from the second neighbor sector, in uplink case the received signal at the BS is the superposition of the desired signal (from TS1) and three interfering signals (from TS2-TS4). Therefore, uplink interference situation depends on the positions of terminals which can severely degrade system performance. Uplink interference is one of the most critical problems of network planning, therefore in the following we restrict our investigations to uplink analysis.

B. Single-frequency CDMA approach

The loss of frame synchronization leads to severe degradation of TDMA system performance. In a frequency-sectorized LMDS system instead of TDMA other methods, like FDMA or CDMA can be applied. The advantage of CDMA systems, however, is the usage of the whole available frequency band, furthermore the loss of synchronization is not so critical if the periodic and aperiodic cross-correlation functions of the codes in the code set are satisfactory enough. Also, applying CDMA frequency sectorization can be avoided assuming the existence of satisfactory number of codes. Additionally, CDMA provides inter-system interference suppression determined by the processing gain. We considered the single-frequency approach, i.e. applying only space sectoring by the 90° BS antennas. The interference situation in single-frequency CDMA PMP networks with 3x3 BSs is depicted in Fig.3. Compared with Fig.1.b the number of interfering TSs has increased significantly. In contradiction to the worst-case uplink situation of four-frequency TDMA system, the received signal at the BS in single-frequency CDMA is the superposition of the desired signal (from TS1) and all interfering signals from the TSs looking to the same direction. However, the inter- and intracell interference can be kept low by applying codes with good properties. Using orthogonal codes, inter- and intracell interference will be totally suppressed. In case of using non-orthogonal codes, multiuser detection can lead to the required BER performance.
III. INTERFERENCE SUPPRESSION WITH MULTIUSER DETECTION

The application of CDMA provides protection against intercell interference, however compared to TDMA with perfect frame synchronization produced additional intracell interference. Multiuser detection aims to remove multiple access interference (MAI) when detecting the desired user by utilizing the knowledge of all spreading codes in the system. Successive- and Parallel Interference Cancellation (SIC, PIC) type MUD schemes are investigated. Assuming a CDMA system with \( K \) users transmitting continuously the received signal is given by

\[
r(t) = \sum_{i=0}^{K} A_i b_i(t) s_k(t - iT - \tau_k) + n(t),
\]

where the \( k^{th} \) user is identified by spreading waveform \( s_k \), \( b_i \) denotes the sent bit with the duration \( T \), \( A_i \) is the received amplitude of the \( k^{th} \) and \( n \) is the white Gaussian noise. Applying a bank of \( K \) matched filters (MF), the output of the \( k^{th} \) filter (MF\(_k\)) for the \( i^{th} \) bit is then

\[
y_k(i) = \frac{1}{T} \int r(t - iT - \tau_k) s_k(t) dt = A_i b_i(t) + \sum_{j=0}^{K} A_j \rho_{j,k} (\tau_k - \tau_j) b_j(t) + n,
\]

where \( \rho_{j,k} \) is the cross-correlation between users \( j \) and \( k \).

The SIC algorithm [6] cancels the MAI successively by despreadening the signal of a previously detected user and subtracting from the remaining signal as can be seen in Fig.4. The SIC receiver ranks the users according to their received signal powers canceling first the higher power users. The detected bit for user \( k \) after canceling \( k-1 \) users is given by

\[
\hat{b}_k(i) = \text{sgn} \left[ \int r(t) - \sum_{j=0}^{k-1} A_j s_j(t - iT - \tau_j) \hat{b}_j(i) s_k(t - \tau_k) dt \right]
\]

The efficiency of PIC and SIC detectors are strongly affected by whether using power control or not. In the following we present our simulation results using single-stage SIC and PIC for interference suppression in single-frequency CDMA-based LMDS systems.

![Fig. 5. Receiver structure of parallel interference cancellation](image)

![Fig. 7. Uplink C/I (a, c) and the corresponding BER (b, d) conditions in the investigated sector for 4-frequency sectorized TDMA for regular and random TS positions (SNR=7 dB)](image)

IV. RESULTS

In this section after introducing our system model, we present the calculated and simulated results of our investigations of uplink interference suppression methods in single frequency CDMA-based LMDS system compared with four-frequency TDMA.

A. System model

We considered the 26 GHz frequency domain with channel separation of 28 MHz for 4 separate sectors. Frequency-division duplexing (FDD) was used. The applied modulation method was BPSK both for
TDMA and CDMA.

Antenna characteristics: In our system model 90° sectors were applied with narrow beam TS antennas. Table 1 gives antenna characteristics according to ETSI recommendation [7].

TS locations: As seen in Section II, uplink interference depends on the number and location of terminals. In our investigations, two simple configurations were taken with only two terminals per sector. Regularly and randomly arranged scenarios were analyzed respectively, displayed by Fig.6., where the squares denote the examined sectors.

Propagation assumption: Free-space LOS propagation conditions were assumed between all of the terminal and base stations, assuming that the signal attenuation is proportional to the square of the distance. All TSs transmit with the same power, leading to a worst case scenario without power control. The received signal levels were calculated from the antenna patterns given in Table 1, with the antennas focused according to the directions depicted in Fig.6. We also assumed the perfect estimation of interfering signal powers.

CDMA codes and receiver structures: For CDMA a code set of 127 chip long Gold codes was used. Both bit-synchronous and asynchronous cases were investigated. When selecting the appropriate BS receiver for CDMA-based LMDS system, we assume central controlling of the network in aware of all users’ spreading codes. Base station receivers therefore can apply detectors, which exploit the knowledge of all spreading codes. In our uplink analysis for comparison SIC, PIC and MF receiver structures were investigated.

B. Numerical results for four-frequency TDMA

The first part of our uplink interference investigations includes numerical calculations of C/I and BER for the previously described four-frequency sectorized TDMA. The resulting sector (marked in Fig.6.) maps for C/I and the corresponding BER are displayed in Fig.7. calculated for regular and random TS positions according to Fig.6. A certain point on the map indicates the interference level on the uplink of a supposed TS installed at that point, caused by the existing TSs of the network. BER values were calculated for a constant SNR=7 dB. Assuming BPSK modulation BER can be simply calculated by BER = 1/2 erfc(\sqrt{C//I(N_0 + I)}) . Results show a slight difference with respect to different TS locations, namely the regular TS arrangement gives better interference situation. The reason for this is that with regular TS arrangement the critical interferer positions, e.g. sector borders and diagonals shown in Fig.1.b were avoided.

C. Simulation results for single-frequency CDMA

Simulation results for the investigated single-frequency CDMA LMDS system include BER sector maps, and BER vs. SNR curves for MF, SIC and PIC receivers for bit-synchronous and asynchronous cases – assuming chip-synchronity. As a worst case scenario, only random TS distribution was considered given in Fig.6.b. The resulting BER sector maps can be seen in Fig.8. The efficiency of TDMA and CDMA for bit-synchronous case can be compared obtaining Fig.7.d and Fig.8.a,c,e. Applying bit-synchronous CDMA we can achieve a slight improvement of BER performance compared to TDMA, as also obtainable in Fig.9., where sector average BER values are given for four-frequency TDMA and single frequency CDMA with MF, SIC and PIC receivers. Even in case of loss of synchronization, which would be critical for TDMA, bit-asynchronous CDMA with MUD can fulfill the system requirements as seen in Fig.8.d,f and Fig.9. However, single-user detection (MF) in bit-asynchronous case (Fig.8.b) also leads to unacceptable BER performance at the TS locations far away from the serving BS. The effect of multiuser detectors is significant particularly in asynchronous cases, please compare in Fig.8. cases b (MF) vs d (PIC) and f (SIC). Canceling the interference with MUD, BER conditions became nearly homogeneous, overcoming the problem of critical TS positions in terms of uplink interference. The efficiency of CDMA detectors were also examined by BER vs. SNR curves even in the existence of extremely high interferers corresponding to C/I values of -20.2 dB and -17.5 dB. Fig.10. and Fig.11. show the BER performance of MF, SIC and PIC receivers in bit-synchronous and asynchronous cases, respectively. In synchronous case (Fig.10.) all of the receivers suppress the interference.
almost equally by lower $E_b/N_0$ values. However, applying SIC or PIC we can achieve approx. 1 dB gain at BER value of $10^{-4}$. The advantage of MUD receivers can be exploited in bit-asynchronous case, as shown in Fig.11. The gain by $10^{-2}$ BER value is approx. 3 dB at $C/I=-20.2$ dB, while 2 dB at $C/I=-17.5$ dB by using PIC or SIC receivers.

V. CONCLUSIONS

In our contribution we investigated the uplink interference situations in single frequency-CDMA based LMDS system applying multiuser detection at the BSs compared with four-frequency sectorized TDMA-based LMDS system. The loss of frame synchronization leads to severe degradation of TDMA system performance, however, CDMA also in bit-asynchronous cases applying MUD fulfills the system requirements, even in poor C/I conditions. Additionally, canceling the interference with MUD, BER conditions become nearly homogenous over the whole sector, overcoming the problem of critical TS positions in TDMA scheme. Applying MUD, therefore, would be a feasible solution, while the additional costs of BS multiuser receivers not dominant. Improving network capacity this way can also lead to simpler and cheaper terminal stations, e.g. needing less accurate antenna focusing. Therefore we propose the application of MUD aided CDMA in future LMDS systems.

Further investigations of multiple access methods, such as multicode CDMA, multi-frequency CDMA, combined CDMA/TDMA solutions together with much more sophisticated MUD algorithms are planned.

REFERENCES