Handover Sequences for Interference-Aware Transmission in Multicell MIMO Networks

Volker Jungnickel, Konstantinos Manolakis, Lars Thiele, Thomas Wirth and Thomas Haustein
Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut
Einsteinufer 37, 10587 Berlin, Germany
jungnickel@hhi.de

***Abstract*—Providing cell-specific reference signals is a basic requirement for advanced transmission techniques reducing the inter-cell interference in the mobile radio network. In this paper, we introduce so-called handover sequences. They consist of a comb cyclically shifted in the frequency domain to identify the cells. Orthogonal sequences in time domain are used to identify the antennas within a cell. The scheme occupies few OFDM symbols per coherence interval. Sequence assignment to the cells follows a classical frequency-reuse scheme. Detection is easily implementable. With these sequences, the frequency-selective multi-cell channel can be identified with high precision also at the cell edge. We demonstrate that handover decisions are more reliable and channel estimation errors are reduced by more than a decade compared to the reference signals provided in 3GPP LTE Release 8.**

I. INTRODUCTION

Interference-aware transmission covers a new class of multi-antenna techniques reducing the inter-cell interference and further enhancing the spectral efficiency in the mobile radio access network. These new techniques can be classified into independent transmission at each base station and cooperative transmission of multiple base stations.

The independent approach has been thoroughly investigated in the multi-cell down-link scenario, refer to [1]. Explicit knowledge of the channel to the best server and to the strongest other base stations is assumed and exploited twice. At the physical layer, optimum combining is used [2]. At the medium access control layer (MAC) layer, knowing the multi-cell channel enables a precise, i.e. frequency-selective, estimation of the signal to interference and noise ratio (SINR). SINR versus frequency vectors after fixed beam forming, wireless channel and optimal combining for single and multiple streams in the cell are quantized and fed back to the base station. Knowledge about the interference improves the performance of fair scheduling algorithms [3], [4]. A striking advantage is the frequent use of multi-stream transmission even at the cell edge.

The cooperative mode receives more attention recently [5], [6]. There is a clear trend to organize it in a distributed manner [7]. Base station cooperation requires instantaneous exchange of channel state information obtained via feedback from the terminals and transferred between the base stations over a meshed backbone network with low latency. In this way, each base station gets global channel knowledge. Moreover, data are synchronously distributed to all cooperative base stations and the joint beam-forming is steered locally [8].

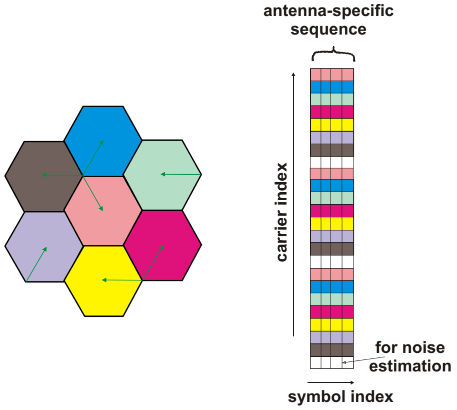

Fig. 1. **Left: Elementary interference scenario. Right: Cells are identified using a comb in frequency domain individually shifted in each cell. Antennas within each cell are identified using time-domain sequences.**

In this paper, we focus on the identification of multiple cells using specific reference signals. We illustrate the advantages of the proposed sequence design for handover decisions and multi-cell channel estimation.

II. REQUIREMENTS AND PREVIOUS WORK

Interference-aware transmission techniques have two requirements in common: 1. Synchronized base stations. 2. Multi-cell reference signals. While synchronization can be realized with moderate effort [9], here we focus on the reference signals.

Release 8 of 3GPP LTE has not paid much attention to these requirements. LTE base stations are not necessarily synchronized. Cell-specific reference signals are defined (primary and secondary synchronization sequence, PSS and SSS) but they cover only part of the entire system bandwidth. Scrambling of channel estimation pilots is cell-specific along the frequency axis and it allows an estimation of the wide-band-averaged SINR in a cell. However, there are no explicit reference signals for estimating the multi-cell channel in a frequency-selective manner [10].

A first proposal of multi-cell pilots is reported in [11]. All cells use pilots at the same positions in the time-frequency grid. Cells are identified by scrambling in the time domain, i.e. there is no additional overhead. Proposed sequences have partial correlation properties, where certain subsets of sequences are orthogonal already over a shorter correlation window. The idea is to assign sequences with shorter correlation windows to closer base stations and those with longer windows to more distant ones. From implementation point of view a large number of potential cells must be tracked simultaneously, which can be rather complex. Sequence assignment in the cellular network is not trivial but manageable. We feel that these virtual pilots are well suited for a rapid adaptation to the interference channel at the receiver side, using techniques such as optimum combining. Note that only a few interfering base stations must be actually tracked to realize most of the gain at the terminal side [12].

III. HANDOVER SEQUENCE DESIGN

In this paper we propose a second set of sequences allowing simpler implementation with almost instantaneous results. These sequences are not transmitted continuously but at a certain period to get a full overview of the multi-cell channel and to identify the most relevant interfering signals in a single shot. Such a design costs additional overhead and it may be suitable for handover decisions, evaluation of the SINR and feedback of the channel state information to the base station. The simple idea is to make cells orthogonal in the frequency domain and to exploit therefore the correlations in the frequency-selective channel. Classical frequency-reuse schemes are then applied to assign sequences to cells.

In a single cell, a handover sequence shall not interfere with another such sequence after passing through the multi-path channel. Definition in the frequency domain is then appropriate. We use a regularly spaced grid of active sub-carriers spanning the entire system bandwidth. For scrambling in the frequency domain, we use a Zadoff-Chu sequence with the same root index as defined in [10] but having a period adjusted to the total number of active sub-carriers in the sequence. Adjacent cells are identified by applying a cell-specific frequency shift of integer multiples of the sub-carrier spacing, see Fig. 1.

Further use of these sequences for interference-aware transmission is intended. Therefore we have to satisfy the fundamental sampling theorem of the channel. Interpolation in the frequency domain is possible if the total number of sub-carriers in the grid is not smaller than the number of resolved multi-path components L in the channel. In OFDM systems, an upper bound for L is given by the length of the cyclic prefix L_{CP}. In case of an 3GPP LTE system with 20 MHz bandwidth, more than $L_{CP} = 144$ pilot tones, scattered over 1.200 sub-carriers, are needed. Accordingly, each 8^{th} sub-carrier is active in the comb.

Next we apply a cyclic shift of the entire comb in the frequency domain by N_{shift} sub-carriers where the shift identifies the cell. With a grid spacing of 8, up to 8 cells can be identified. Consider the elementary interference scenario and the sequence assignment in Fig. 1. Each of the 7 cells is identified by a certain shift $N_{shift} = 0...6$. Note that 7 is a magic number in the hexagonal deployment. It allows the reuse of the sequence in the second one after the next cell where the interference is significantly reduced due to path-loss and down-tilt of the antennas. Reuse of sequences and the resulting interference scenario for the pilots can be characterized by the frequency reuse factor $F = 7$. Sub-carriers at $N_{shift} = 7$ are not used at all. Such empty resources allow a precise noise estimation.

In modern cellular systems, we need to identify multiple antennas in each cell in addition. Therefore we concatenate a few OFDM symbols having the same comb structure and the same cyclic shift in one cell. On a given sub-carrier in the comb, an antenna-specific reference sequence is transmitted along the time domain over as many OFDM symbols as there are antennas in the cell. Estimation is based on a cross-correlation along the time axis on each sub-carrier in the comb. This technique is widely used for the high-throughput long training field (HT-LTF) in the IEEE 802.11n wireless LAN standard.

IV. PERFORMANCE EVALUATION

We have evaluated the performance in two ways. Firstly, we consider the handover fail rate, i.e. the probability that a false cell is detected. Secondly, we examine the channel estimation error in the presence of interference. Our evaluation is based on the 3GPP LTE Release 8 specification. At the receiver, the terminal applies OFDM symbol synchronization using the cyclic prefix. The radio frame start is then identified using the primary synchronization sequence (PSS). Next the terminal applies an FFT of the incoming sequences from multiple base stations.

A. Handover fail rate

The narrow-band PSS in LTE Release 8 is jointly transmitted with data in other parts of the spectrum while the comb is exclusively transmitted over the entire spectrum. For handover detection, autocorrelation with the cell-specific Zhadoff-Chu sequences is applied in the frequency domain and the peak magnitudes are compared. As a reference indicating the strongest cell, in the simulation we have separately measured the power received from each base station (which is not possible in practice, of course). From the autocorrelation peaks, the decision is derived in the presence of interference and compared to the reference. The fail rate is given by the percentage of wrong decisions. It is a monotonous function of the signal-to-interference ratio (SIR). The higher the SIR is the more likely handover decisions are correct.

B. Channel estimation error

For coarse channel estimation, cross-correlations along the time axis in Fig. 1 are applied with all antenna-specific sequences and at each receive antenna. Next the channels are interpolated in the frequency domain using a linear MMSE estimator. Interpolation in the time domain is not included in results. As an upper bound, perfect knowledge of both the signal to noise ratio (SNR) and the power delay profile is assumed for building the interpolation matrix.

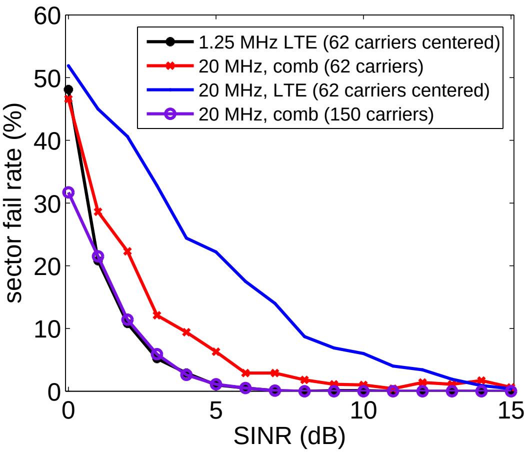

Fig. 2. **Reliability of handover decisions.**

We are most interested in comparing the estimation performance with LTE Release 8 where other cells transmit data on pilot positions in the desired cell. This is equivalent to having a frequency reuse factor of $F = 1$ during the channel estimation. Estimating the channel from an adjacent cell is interfered by the stronger data signals in the serving cell. The estimation error for negative SIR thus gives an impression of the corresponding performance degradation. For the comb sequences, there is no interference from data signals in other cells. Interference comes from the pilots of rather distant cells using the same cyclic shift for their comb. For evaluating the estimation performance, a frequency reuse factor of $F = 7$ is appropriate.

V. RESULTS

A. *Handover fail rate*

We have tested the reliability of handover decisions in 1.25 and 20 MHz LTE systems using 3 cells at one site. A terminal is moved across the border between two sectors and the third sector points away. Random multi-path channels are used and instantaneous powers are considered.

At first we have considered the 62 sub-carriers wide PSS in [10], where other resource blocks (RBs) are filled with data. The second prototype is a comb with 62 sub-carriers in 20 MHz with data on intermediate sub-carriers. The original Zadoff-Chu sequence [10] is spread over the comb. Thirdly, the comb with 8 sub-carriers spacing is used where the presence of other base stations is emulated by random data signals on intermediate sub-carriers. Results for the handover fail rate are given in Fig. 2.

The fail rates r can be empirically modeled as

$$r = a * exp\left(-\frac{SIR}{SIR_0}\right) \tag{1}$$

with the parameters

System	a [%]	$SIR_0[dB]$
1.25 MHz LTE	50	1.8
20 MHz LTE	52	5
20 MHz 62 carriers	45	2.5
20 MHz 150 carriers	32	1.8

Good performance is achieved in the 1.25 MHz system where almost the full system bandwidth is also covered by the PSS. But if the system bandwidth is larger than the fixed PSS bandwidth [10], e.g. in the 20 MHz system, the performance gets worse. In 35 % of cases, a false server may be identified although the best cell has 3 dB more power. This is attributed to the frequency-selective fading temprorarily causing a lower-than-average power level in the limited bandwidth tested by the PSS. A good handover sequence should therefore probe the entire signal bandwidth. This is fulfilled for the comb. With 20 MHz and 62 subcarriers in the comb, the performance is already close to the 1.25 MHz case. With 20 MHz and 150 subcarriers in the comb, reliablility is further improved. Only in 5 % of cases the false cell is identified as the server if the best cell has 3 dB more power.

B. *Channel estimation error*

The channel estimation performance has been quantified for a 20 MHz LTE system where a single OFDM symbol contains 200 pilots. Note that the mean-square error (MSE) depends on the channel length. We can approximate the MSE as

$$MSE = \frac{G}{SIR} \tag{2}$$

where G denotes the estimator gain. In a multi-path Rayleigh fading channel with L independently and identically distributed taps, G is given by

$$G = \frac{N_{sc}}{d * L} \tag{3}$$

where N_{sc} is the total number of subcarriers and d the pilot spacing. The actual value of G can be read off from graphs like in Fig. 3 at $SNR = 0\ dB$ also for more realistic channel models. We have considered an exponential power decay profile over the entire cyclic prefix with a decay time of 2.3 μs to model a strongly shadowed NLOS channel which is a rather likely at the cell edge. Note that the kinks in the graphs come from using interpolation matrices in coarse SNR steps of 5 dB only. The resulting estimator gain G is obtained at 5 dB and 6 dB for LTE and the comb, respectively, due to the slightly smaller pilot density. The estimator gain is of course enhanced for shorter channels.

In the multi-cell environment, the channel estimation error follows the SIR statistics in general. The user experiences different SIR at different positions in the cell. Accordingly, the estimation error statistics can be modeled as

$$\rho_1(MSE) = \rho\,(SIR) * \left|\frac{dSIR}{dMSE}\right|. \tag{4}$$

Using the model for the MSE from above we obtain

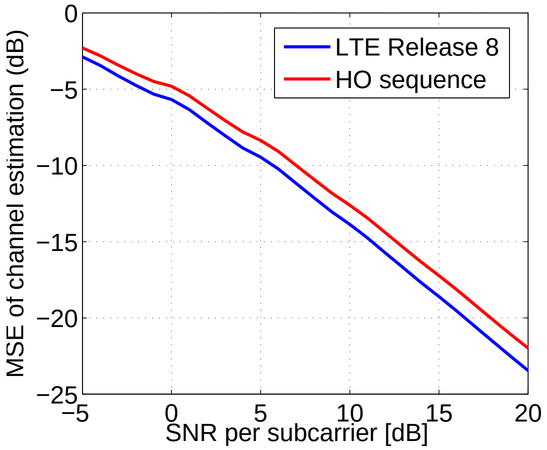

Fig. 3. **Channel estimation performance**

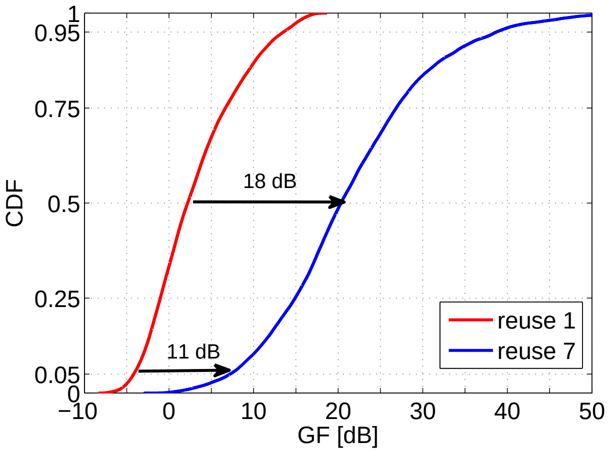

Fig. 4. **Geometry factor for frequency reuse 1 and 7.**

$$\rho_1(MSE) = \rho\left(\frac{G}{MSE}\right) * \frac{G}{MSE^2}. \tag{5}$$

The statistics depends significantly on the frequency reuse factor F. This causes a striking difference between the LTE pilot structure and the comb. A frequently used measure for the carrier-to-interference situation within a cell is the geometry factor

$$GF = \frac{\mathbb{E}(P_{signal})}{\mathbb{E}(P_{interference})}. \tag{6}$$

In Fig. 4, the geometry factor is shown for $F = 1$ and $F = 7$ in a hexagonal deployment with 57 sectors where each base station has three sectors. Obviously, the SIR is much higher with frequency-reuse, and thus the channel estimation is enhanced. From Fig. 4, we may read off the 5 and 50 percentiles of the cumulative geometry statistics to estimate the MSE at the cell edge and on average in the cell, respectively. Corresponding values are -2 dB and -8 dB for LTE Release 8 using $F = 1$ and -12 dB and -25 dB, respectively if the proposed comb is used with $F = 7$.

VI. CONCLUSIONS

We have proposed cell-specific reference signals which can be used for both handover decisions and multi-cell channel estimation. The proposed sequences consist of a comb in the frequency domain. Shifting the comb by integer multiples of the sub-carrier spacing identifies the cell. The frequency response of the channel can be estimated below a maximum spacing in the comb depending on OFDM symbol duration and cyclic prefix length. For sequence assignment in a full-coverage cellular network, classical frequency-reuse concepts can be used up to a reuse factor equal to the spacing. The handover fail rate is reduced in this way and the precision of the channel estimation is enhanced by 10 dB and 17 dB at the cell edge and on average in the cell, respectively, using a comb spacing of 8 and a frequency reuse factor of 7.

VII. ACKNOWLEDGMENTS

This authors are grateful for financial support by the German Ministry of Education and Research (BMBF) in the national research project EASY-C under contract 01BU0631.

REFERENCES

[1] L. Thiele, M. Schellmann, W. Zirwas, and V. Jungnickel, "Capacity scaling of multi-user MIMO with limited feedback in a multi-cell environment," in *41st Asilomar Conference on Signals, Systems and Computers*. Monterey, USA: IEEE, Nov. 2007, invited.

[2] J. Winters, "Optimum combining in digital mobile radio with cochannel interference," *IEEE Journal on Selected Areas in Communications*, vol. 2, no. 4, pp. 528–539, 1984.

[3] L. Thiele, M. Schellmann, T. Wirth, and V. Jungnickel, "Interference-aware scheduling in the synchronous cellular multi-antenna downlink," in *69th IEEE Vehicular Technology Conference, 2009. VTC 2009-Spring.*, May 2009, invited.

[4] V. Jungnickel, M. Schellmann, L. Thiele, T. Wirth, T. Haustein, O. Koch, W. Zirwas, and E. Schulz, "Interference aware scheduling in the multiuser mimo-ofdm downlink," *IEEE Communications Magazine*, June 2009.

[5] P. Baier, M. Meurer, T. Weber, and H. Troger, "Joint transmission (jt), an alternative rationale for the downlink of time division cdma using multi-element transmit antennas," in *Spread Spectrum Techniques and Applications, 2000 IEEE Sixth International Symposium on*, vol. 1, 2000, pp. 1–5 vol.1.

[6] M. Karakayali, G. Foschini, and R. Valenzuela, "Network coordination for spectrally efficient communications in cellular systems," *Wireless Communications, IEEE*, vol. 13, no. 4, pp. 56–61, Aug. 2006.

[7] W. Zirwas, E. Schulz, J. H. Kim, V. Jungnickel, and M. Schubert, "Distributed organization of cooperative antenna systems," in *European Wireless, Athens, Greece*, Apr. 2006.

[8] V. Jungnickel, L. Thiele, M. Schellmann, T. Wirth, A. Forck, W. Zirwas, T. Haustein, and E. Schulz, "Implementation concepts for distributed cooperative transmission," *42nd Asilomar Conference on Signals, Systems and Computers*, Oct. 2008.

[9] V. Jungnickel, T. Wirth, M. Schellmann, T. Haustein, and W. Zirwas, "Synchronization of cooperative base stations," in *IEEE International Symposium on Wireless Communication Systems 2008 (ISWCS08)*, Reykjavik, Iceland, Oct. 2008.

[10] 3GPP TS 36.211 V8.0.0, "E-UTRA - physical channels and modulation (release 8)," Sept. 2008.

[11] L. Thiele, M. Schellmann, S. Schiffermller, and V. Jungnickel, "Multi-cell channel estimation using virtual pilots," in *IEEE 67th Vehicular Technology Conference VTC2008-Spring*, Singapore, May 2008.

[12] L. Thiele and V. Jungnickel, "Adaptive transmission in a realistic multicell scenario," in *IEEE Radio and Wireless Symposium*, Jan. 2008.