Multi-Antenna Processing in the WINNER Air Interface

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Abstract

This paper summarizes work on multi-antenna processing that has been carried out in the European research project WINNER (Wireless World Initiative New Radio). An overview of the WINNER multi-antenna concept is given, and its preferred configurations and their performance in two different deployment and propagation scenarios are presented. The WINNER multi-antenna concept is a generic and flexible MIMO transmission framework, capable of realizing configurations suitable to a wide range of scenarios. For a *wide area* scenario, it is shown that SDMA (Spatial Division Multiple Access) based on a fixed beamforming scheme, a so-called *Grid-of-Beams*, is able to capture most of the available gain in the spatial domain. In a *local area* scenario on the other hand, where large amounts of high quality channel knowledge can be acquired, it is shown that the combination of SDMA and spatial multiplexing achieved by advanced *multi-user MIMO precoding* efficiently exploits the spatial domain and provides high performance.

1. Introduction

The European research project WINNER [1] has been running since 2004 with the vision of a single ubiquitous next generation radio access system concept scalable and adaptable to a comprehensive range of mobile communication scenarios. It should have enhanced capabilities compared to existing systems or their evolutions in order to provide users with high quality of service wireless access, while at the same time being spectrally efficient and allowing a cost-efficient deployment. The main objectives are increased data rates, low latency, and high system capacity. Advanced multi-antenna processing is a key enabler to meet these targets. The use of multiple antennas at transmitters and receivers in a wireless communication system offers additional degrees of freedom since it allows utilizing the spatial domain. It implies that reception and transmission in different directions may be controlled, redundancy in the spatial domain may be used, and that the radio resources may be reused for parallel transmissions to one or several users.

This paper summarizes the work that has been carried out in the area of multi-antenna processing in WINNER. It gives an overview of the WINNER multi-antenna concept, and presents suitable configurations of it and how they perform in two different deployment and propagation scenarios.

2. Overview of the WINNER Air Interface

The WINNER air interface is a packet-oriented user centric concept. It targets bandwidths up to 100 MHz, and supports both frequency division duplex (FDD) and time division duplex (TDD) operation. Key components of the concept are *multi-antenna processing, relaying, flexible spectrum usage* (e.g. spectrum sharing with other systems), and *adaptive transmission schemes*. The design is based on (standard or precoded) OFDM transmission in both downlink and uplink. The basic resource unit is denoted a *chunk* and comprises a set of adjacent subcarriers and (time) symbols. Such a chunk is the smallest unit that can be scheduled for transmission, and the chunk size is chosen so that the channel variations within a chunk are negligible. Multi-antenna processing allows reuse of each chunk, via so-called *chunk layers*. A *frequency-adaptive* transmission mode coexists with a *non-frequency adaptive* mode. In the frequency-adaptive mode channel dependent scheduling provides multiuser diversity and the transmissions are adapted according to the short term channel fading and interference fluctuations. Adaptation may be performed in the time, the frequency, and the spatial domains. In the non-frequency adaptive mode only the long term channel and interference variations are accounted for. For further details on the WINNER air interface, see [2].

3. The WINNER Multi-Antenna Concept

The WINNER multi-antenna concept is a generic and flexible MIMO transmission framework based on *per stream rate control*, *linear dispersion codes* and *linear precoding*, which allows flexible combinations of *directivity*, *diversity*, and *multiplexing* to be realized in an adaptive manner [3]. The main idea is to adapt the transmission to the user needs in different deployments and conditions based on channel and interference knowledge obtained by measurements, feedback and exploitation of reciprocity.

Fig. 1 shows a block diagram of the generic multi-antenna transmit processing. At the input of the transmitter are the incoming data transport blocks from higher layers. Each of these transport blocks is segmented and channel encoded in a forward error correction entity. These encoded segments of transport blocks are multiplexed onto chunk layers. The bits mapped to each chunk layer are separately modulated. The so formed modulated chunk layers are then dispersed or spread onto virtual antenna chunks with a linear dispersion code which is a three-dimensional entity spanning the adjacent subcarriers of the consecutive OFDM symbols in time and frequency corresponding to the chunk in addition to the spatial dimension which has been added. All virtual antenna chunks are then subject to generalized multicarrier (GMC) processing. The GMC function operates on an OFDM symbol basis in the frequency domain over all chunks allocated to a transport block. More specifically, the layers of virtual antenna chunks are jointly processed by an identity function (when OFDM is used) or a discrete Fourier transform (DFT) function (in the case of precoded OFDM) and then split and dispersed over the virtual antenna chunks again. The virtual antenna chunk of each layer is further subject to linear precoding. Finally, the layers' antenna chunks are summed over the antennas to form a three-dimensional antenna chunk, which is passed to assembly and OFDM modulation per antenna.

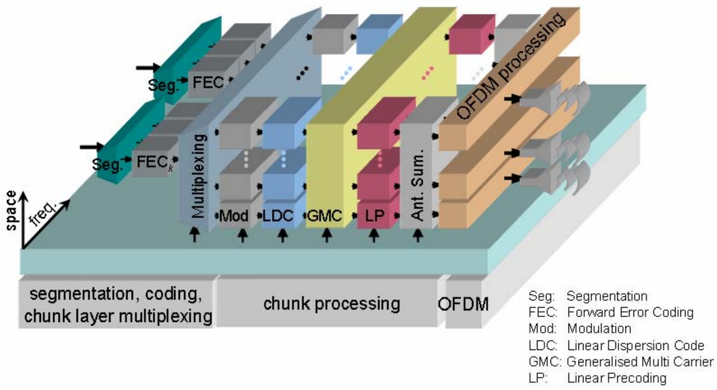

Figure 1: Generic multi-antenna transmit processing.

Depending on the scenario, system load, propagation conditions, and number of receivers (unicast, multicast or broadcast), varying multi-antenna processing gains (multiplexing, diversity, and directivity) will be exploited to different degrees and therefore different multi-antenna transmission schemes will be applied. In a particular scheme not all of the above function blocks will be operational. Thus, arbitrary combinations of the function blocks for segmentation, linear dispersion coding, and linear precoding may be used.

In order to efficiently exploit the capabilities and the flexibility of the generic transmitter the corresponding receivers must typically be equipped with several receive antennas. Multiple receive antennas are e.g. required for efficient spatial multiplexing and are also important in order to improve the diversity and the robustness to interference since it allows implementation of interference rejection techniques in the receivers.

4. Multi-Antenna Configurations in Different Scenarios

As mentioned above, the WINNER system should be adaptable to a wide range of mobile communication scenarios. For this purpose, a number of different test scenarios were defined in WINNER [4]. In particular, the most efficient multi-antenna transmission scheme is highly dependent on the scenario and propagation conditions. In this section, we will identify suitable configurations of the WINNER multi-antenna concept in two of the defined scenarios; a typical *wide area* scenario and a typical *local area* scenario.

4.1 Wide Area

The WINNER system configuration for wide area shall provide ubiquitous coverage for rural, suburban, and urban areas. It is characterized by medium to large cell coverage where the users may move at very high speeds. The considered test scenario is an urban macro-cellular deployment using the FDD physical layer mode, a carrier frequency of 3.7 / 3.95 GHz and 2 x 50 MHz bandwidth. A traditional hexagonal cell layout is considered with three-sector sites, a site-to-site distance of 1000 m, and antennas mounted above roof top level. In such a scenario, typically the angular spread is low and the antenna correlations are large, which results in a low rank channel matrix. Multi-antenna schemes in this type of scenario have to be robust and to cope with these typical environmental properties. Short-term channel state information (CSI) (e.g. transmit covariance matrix) of reasonable quality will not be available at the transmitter as user mobility is non-negligible and the feedback bandwidth and delay are limited. On the other hand, for low to medium user velocities scalar channel quality indicators (CQI) can be used on a fast fading granularity.

These environment characteristics suggest that linear precoding (i.e. beamforming) schemes are suitable candidates. The simplest form is fixed beamforming, in which a finite set of antenna weights is used which generates a set of pre-defined beams. This means that the beamforming problem reduces to beam selection. In WINNER, a four-element uniform linear array (ULA) has been used to form eight fixed beams, a so-called *Grid-of-Beams* (GoB) [5]. This configuration has been shown to provide a significant gain compared to single antenna transmission, as illustrated in Fig. 2 which shows the 5th percentile of the user throughput plotted versus the spectral efficiency per sector for different number of users. At a satisfied user criterion of 2 Mbps user throughput at the cell border (5th percentile), SISO gives a sector spectral efficiency of 1.3 bps/Hz, while GoB gives almost 2.2 bps/Hz. Going to more advanced adaptive beamforming schemes (not shown in Fig. 2) gives nearly no additional gain [5]. A promising solution is instead to implement spatial division multiple access (SDMA) based on the GoB, i.e. to allow reuse of the radio resources for transmissions to users in different beams. This improves the sector spectral efficiency to 2.5 bps/Hz. All these results assume user terminals with two receive antennas and maximum ratio combining (MRC). With more advanced receive combining techniques it is possible to reach almost 3 bps/Hz [6]. An interesting alternative configuration is to use two sub-arrays (e.g. two cross-polarized antennas) instead of the four-element ULA. This allows combinations of spatial multiplexing and beamforming, which is called SU MIMO switching in Fig. 2. However, as can be seen this combination does not exceed the performance of SDMA based on GoB, but has the benefit of facilitating multiplexing of several streams to one user when the conditions allow it and thereby increasing the user peak data rate.

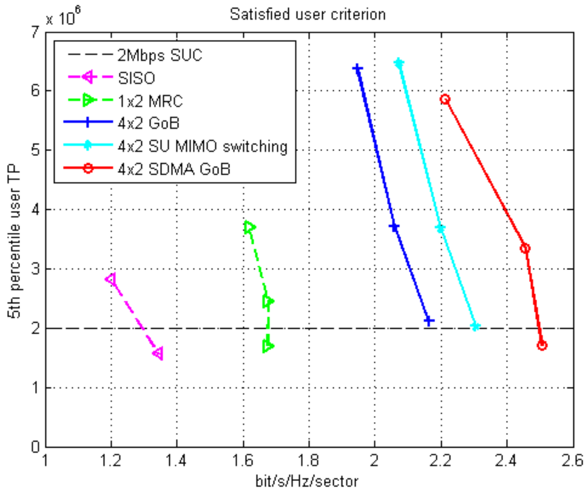

Figure 2: Spectral efficiency in wide area, with a satisfied user criterion of 2 Mbps user throughput at the cell border (5th percentile).

4.2 Local Area

The WINNER system configuration for local area targets isolated sites in indoor and hotspot scenarios. It is characterized by low user mobility (up to 5 km/h), high data rate provision, and high traffic demand. The scenario under investigation is an indoor deployment using the TDD physical layer mode and 100 MHz bandwidth at 5 GHz. The considered deployment consists of one office floor (height 3 m) containing two corridors of 5 m x 100 m and 40 rooms of 10 m x 10 m, see Fig. 3. Such a scenario is characterized by high shadowing and considerable signal attenuation due to the existence of rooms separated by walls. As a result of its isolated characteristic it also features low interference from other cells when compared to the outdoor cases. A distributed antenna system is deployed in the form of four 8-element ULAs. TDD operation and low

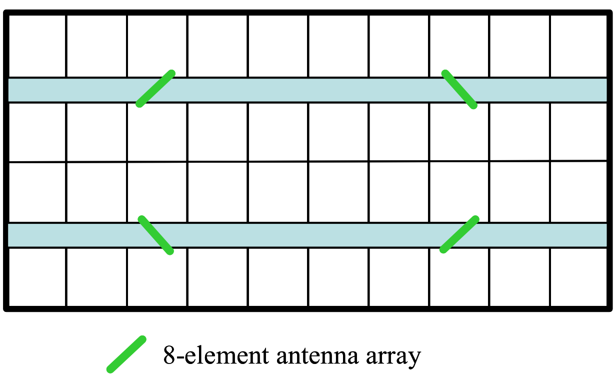

Figure 3: Local area deployment (indoor office floor with a distributed antenna system).

mobility allow estimation of reliable short-term CSI at the transmitter based on uplink measurements and the reciprocity principle. Hence, advanced *multi-user MIMO precoding* schemes, e.g. *successive minimum mean square error* (SMMSE) or *regularized block diagonalization* (RBD) precoding [7], can be used. These techniques exploit short-term CSI at the transmitter to multiplex streams to several users in order to provide high performance. This gain is especially pronounced when the user correlation is low, which is the case in the rich scattering indoor radio environment with distributed antenna deployment.

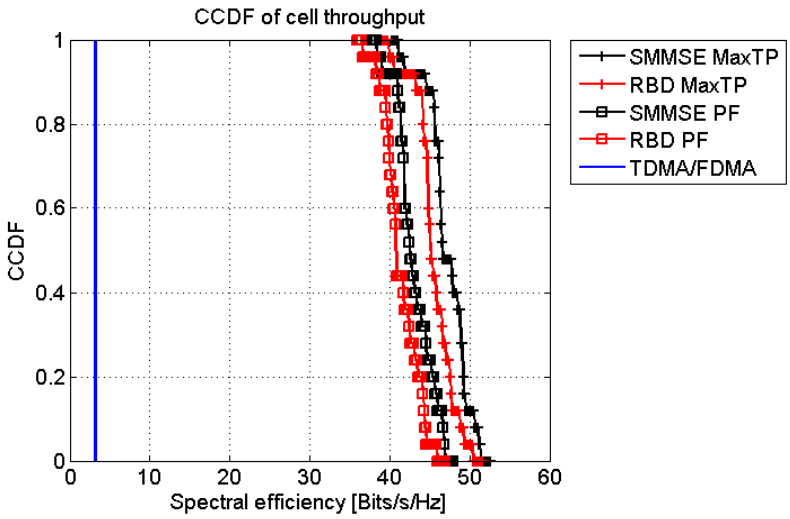

Figure 4: CCDFs of the cell throughput in local area.

Fig. 4 shows complementary cumulative distribution functions (CCDF) of the cell throughput for SMMSE and RBD precoding. The investigations have shown that it is possible to multiplex 20-30 streams and as seen in Fig. 4 the system with 32 transmit antennas operated as four 8-element arrays is able to provide more than 40 bps/Hz.

5. Conclusion

In this paper, an overview of the WINNER multi-antenna concept was given, and its preferred configurations and their performance in two different deployment and propagation scenarios were presented. In a wide area scenario it was shown that SDMA based on a GoB scheme is the preferred configuration, while in a local area scenario advanced multi-user MIMO precoding schemes are suitable configurations.

6. Acknowledgments

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