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Implementation of a precoding algorithm combined with adaptive beamforming for downlink MU-MIMO system

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Purpose

❖ Propose a new precoding method which includes an adaptive beamforming as well as channel inversion in MU-MIMO system.

- Through a hardware implementation of the proposed technique, we demonstrate that the Multiple Access Interference, which can be mitigated by the precoding technique, can further be reduced by appending a beamforming procedure in MU-MIMO system in which various users share a given channel resource.

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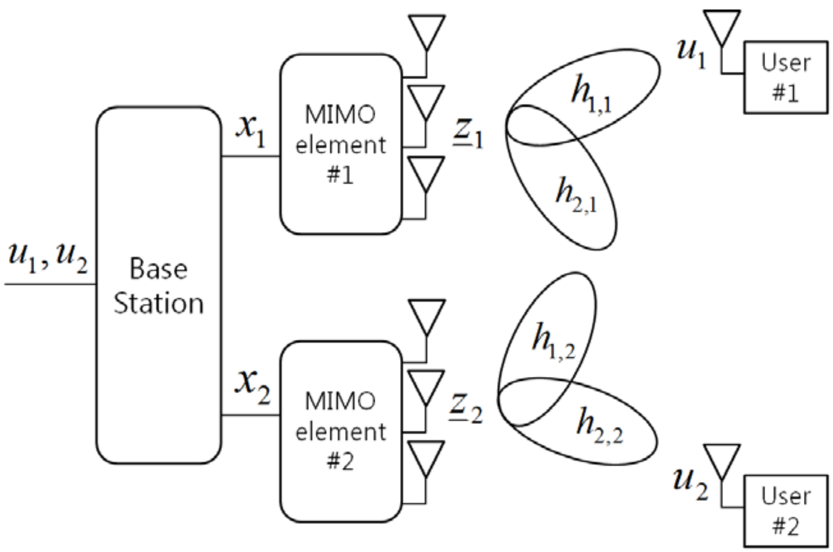
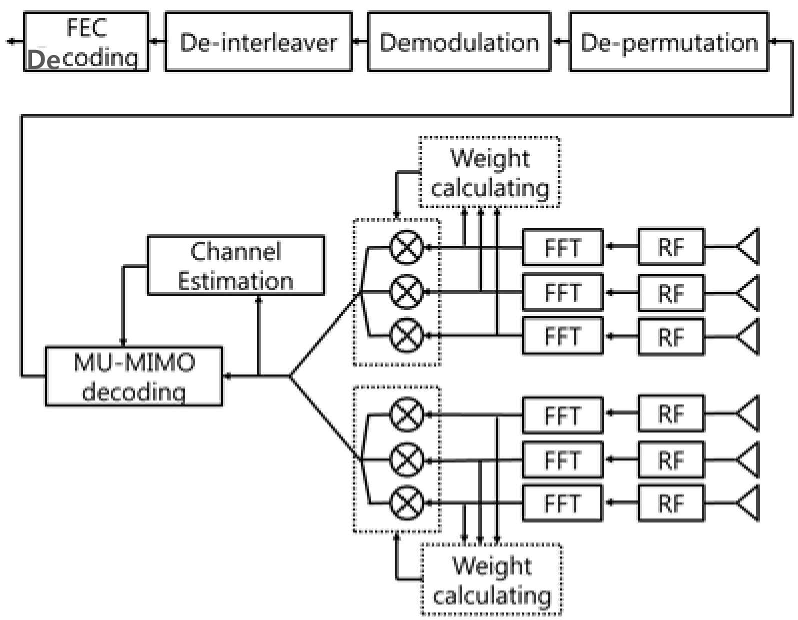
System Model

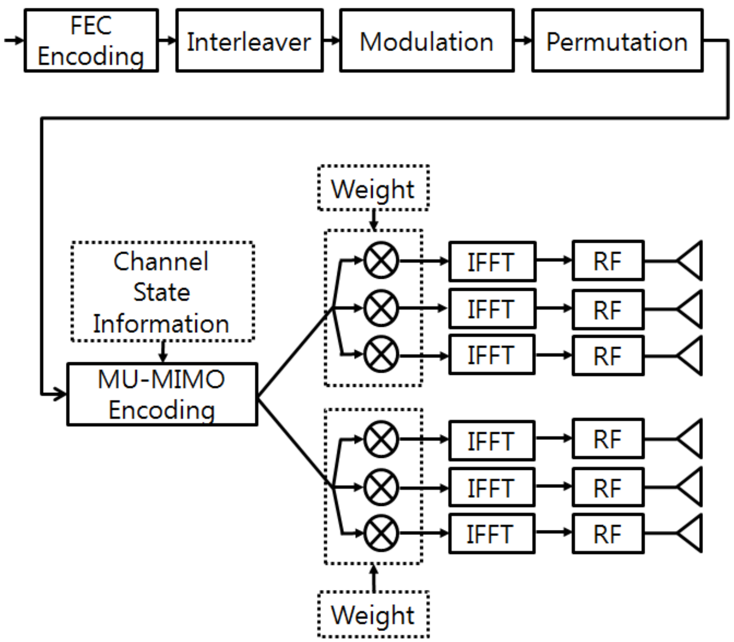


Parameters	Base-Station	User
Number of antennas	3*2	1
Precoding	ZF	
Beamforming	OLB algorithm	
Waveform	WiBro (IEEE 802.16e)	
FEC	Convolutonal Turbo Coding, R=1/2	
Frame Duration (DL/UL)	3.1104 ms / 1.728 ms (for 5 ms)	
TTG/RTG	121.2 μs / 40.4 μs (161.6 μs)	
FFT size	1024	
Number of symbols (DL/UL)	27 / 15	
Modulation Scheme	16QAM	

- Diagram of the system model
- Parameters of the system

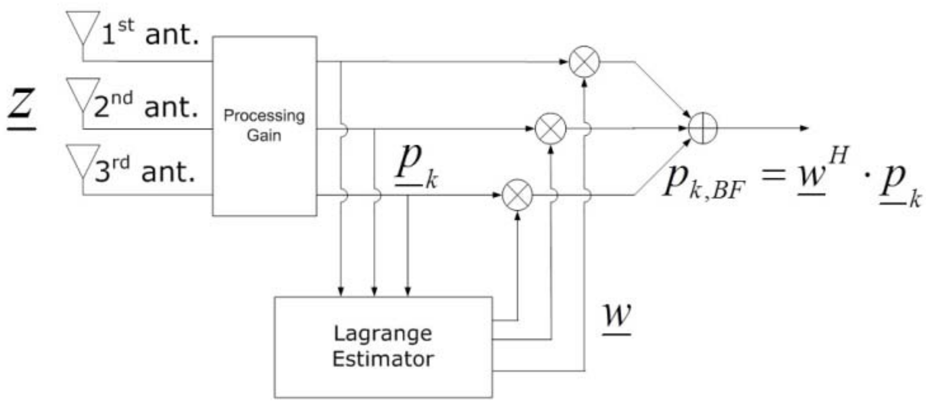
Required Procedure for Realizing the Proposed System





- Uplink
- Downlink

Beamforming Algorithm



- $\underline{Z}$ is a received signal vector at array antenna
- $\underline{w}$ is a weight vector
- $\underline{p}_k$ is a pilot vector belongs to the kth user.
- $p_{k.BF}$ is a pilot signal with a beamforming gain

- Block Diagram of Beamforming System

- OLB algorithm
  - To find $\underline{w}$ maximizing $p_{k,BF}$
  - $\underline{\underline{R}}_{zz}(n)$ is an auto-covariance of the signal vector
  - μ denotes an adaptive gain, which is a major factor for determining the convergence speed

$$\underline{\underline{R}}_{zz}(n) = f \cdot \underline{\underline{R}}_{zz}(n-1) + \underline{z}_i(n) \cdot \underline{z}_i^H(n) \qquad (1)$$

$$\underline{\nabla}(n) = 2\left(\underline{\underline{R}}_{zz}(n) \cdot \underline{w}_i(n-1) - \gamma(n) \cdot \underline{w}_i(n-1)\right) \qquad (2)$$

$$\gamma(n) = b \pm \sqrt{b^2 - ac} / a \qquad (3)$$

$$(\text{where } a = \mu,$$
$$b = \mu \underline{w}_i^H(n-1) \cdot \underline{\underline{R}}_{zz}(n) \cdot \underline{w}_i(n-1),$$
$$c = b + 2\underline{w}_i^H(n-1) \cdot \underline{\underline{R}}_{zz}(n) \cdot \underline{w}_i(n-1))$$

$$\underline{w}_i(n) = \underline{w}_i(n-1) + (1/2)\mu \cdot \underline{\nabla}(n) \qquad (4)$$

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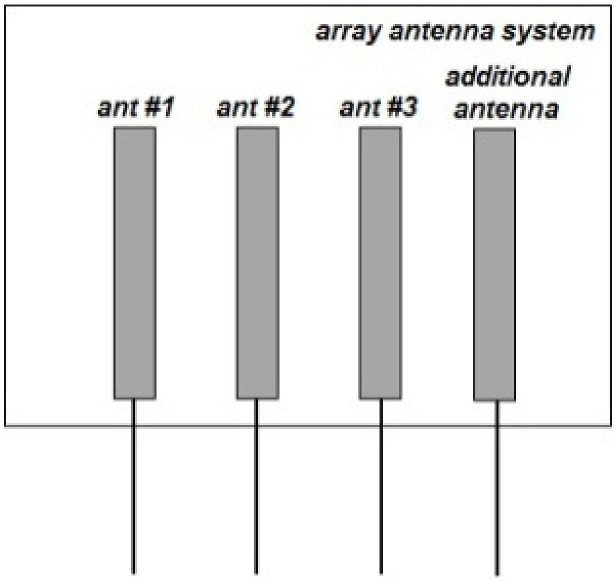
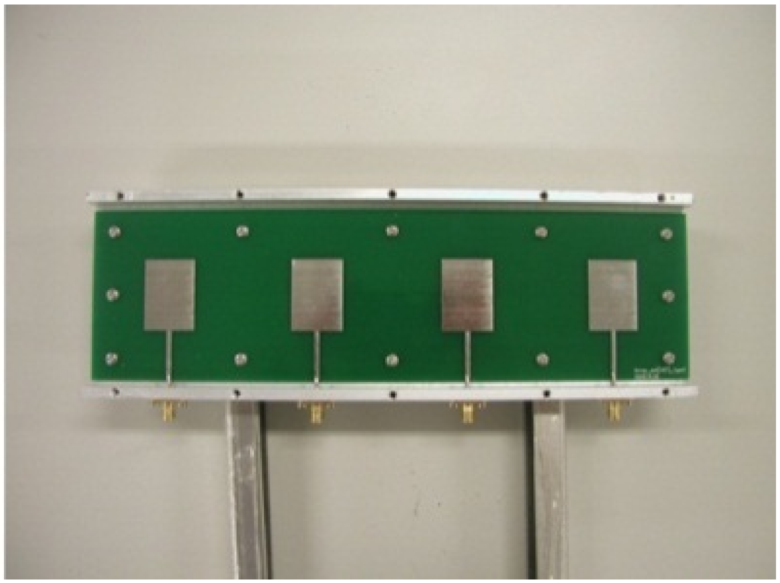
Implemetation (1 / 4)

❖ Array Antenna System added the calibration antenna





- Additional antenna is utilized for transmitting or receiving a test signal to or from each antenna for RX and TX calibration
- The implemented calibration technique can be applied while the array antenna system is operating
  - Test signal which is orthogonal to RX/TX signal is required for real-time calibration
- The phase between the calibration antenna and each of the array antenna is measured in advance

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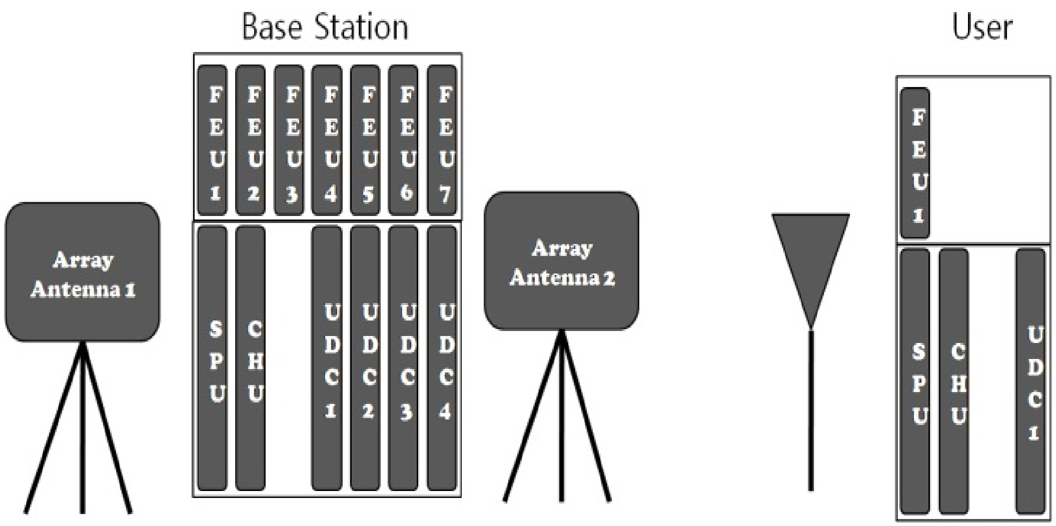
Implementation (2/4)

❖ Overall system architecture



- RF signal is processed in Front-End Unit (FEU)
- System Processing Unit (SPU) and Channel Card Unit (CHU) controls and processes the signals

Implementation (3/4)

❖ Implemented CHU

- It performs the modem functionality of WiBro, i.e., we implement the proposed algorithm in the channel card unit.

- CHU consists of a GPP (MPC8280), 8 DSPs (TMS320C6416T) and 2 FPGAs (ALTERA StratixII).

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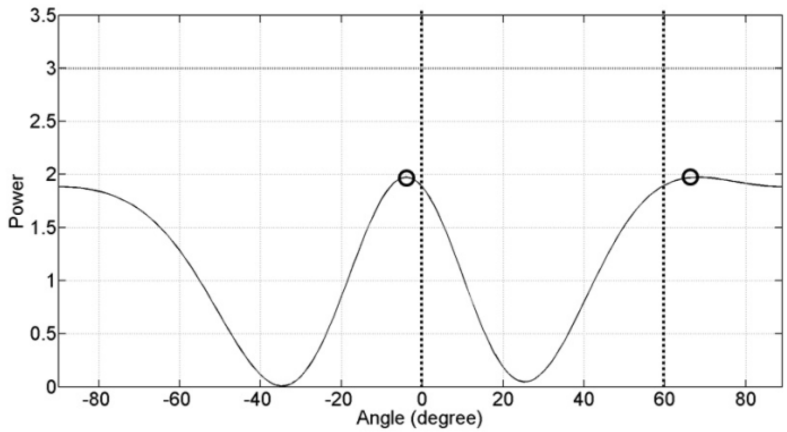
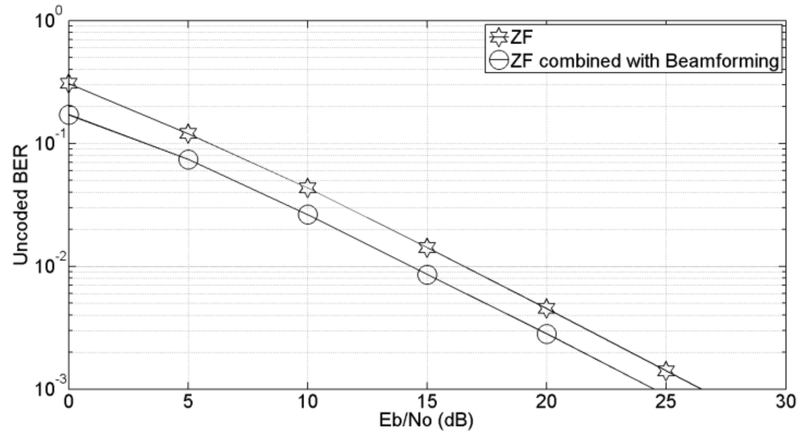
Implementation (4/4)

❖ Implemented MU-MIMO Test-bed

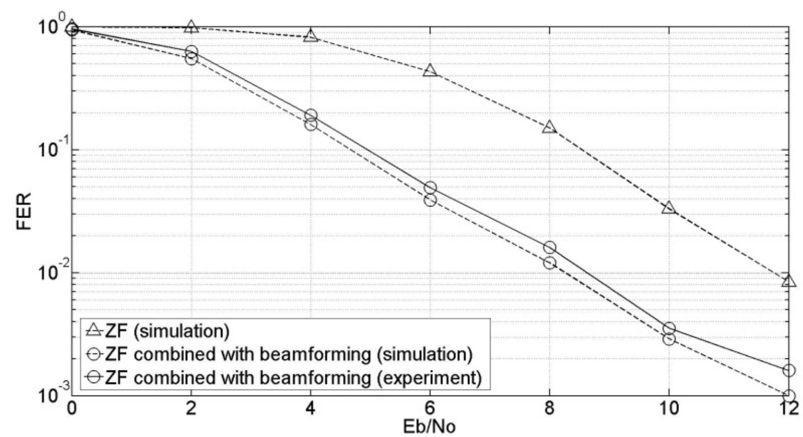
Results



- Beam Pattern Provided by 3-element Array (2 users Located at 0° and 60 °)



- (Simulation result) BER of MU-MIMO System with ZF only and ZF with Beamforming



- (Experiment result) Measured FER performance

Complexity

	Device	Functions	Complexity (K Gates)
Uplink	FPGA	Timing synchronization	597.9
		Frequency Synchronization	614.3
		FFT	338.2
		CP Removal	8.3
		Ranging code Correlator	21.9
	DSP-1	Delay Estimation	-
		Ranging Code Detection	-
		Weight Calculation	-
	DSP-2	Channel Estimation	-
		MIMO detection	-
	DSP-3	Demodulation	-
		FEC decoding	-
		De-Interleaving	-
Total logic gates			1580.6
Downlink	FPGA	Weight Multiplication	376.8
		IFFT	638.2
		Permutation	58.9
		CP Addition	11.4
		Preamble	14.2
	DSP-1	Calibration	-
	DSP-2	MIMO Encoding	-
	DSP-3	Modulation	-
		Concaternation	-
	DSP-4	Randomization	-
	DSP-5	FEC	-
		Interleaving	-
Total logic gates			1099.5

Conclusion

❖ The experimental environment includes a single base station and 2 users, while the base station employs the proposed technique of ZF-based precoding (for 2 MIMO elements) and OLB-based beamforming (for 3-element beamforming for each of the 2 MIMO element), while each user is equipped with a single antenna.

The proposed method

- provides a doubled throughput compared to the SISO
- reduces a transmit power by a half compared to the conventional MU-MIMO system with precoding only.

❖ The proposed method seems to be a good solution for increasing throughput with a given frequency band.


Thank you