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Interference Alignment and Co-Ordinated Multi-Point with 802.11ac-feedback: Testbed Results

Per Zetterberg

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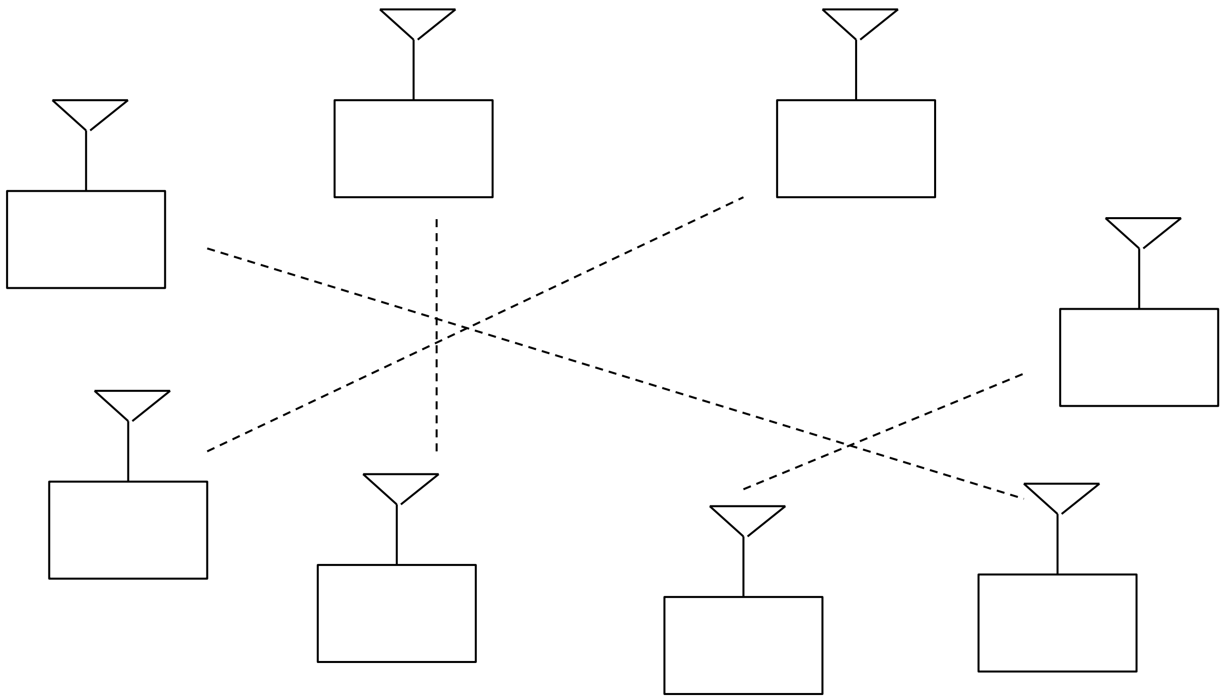
Astonishing Result



Cadambe/Jafar, ”**Interference Alignment and Degrees of Freedom of the K-User Interference Channel”, IEEE Trans, Information Theory 2008.**

K-transmitters and K-receivers, K-links:
K/2 simultaneous interference-free links.
Requires coding over multiple channel realizations.
Global channel knowledge required.

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Channel extension (Cadambe/Jafar)

$$\bar{\mathbf{Y}}^{[i]} = \bar{\mathbf{H}}^{[i1]}\bar{\mathbf{V}}^{[1]}\mathbf{X}^{[1]} + \bar{\mathbf{H}}^{[i2]}\bar{\mathbf{V}}^{[2]}\mathbf{X}^{[2]} + \bar{\mathbf{H}}^{[i3]}\bar{\mathbf{V}}^{[3]}\mathbf{X}^{[3]} + \bar{\mathbf{Z}}^{[i]}$$

$$H^{[ij]} = diag\left(h^{ij}\left(f_1, t_1\right), \cdots, h^{ij}\left(f_m, t_m\right)\right)$$

Channel extended MIMO channel (my wording)

$$m = 2n+1$$

$$\frac{3n+1}{2n+1} \Rightarrow 1.5$$

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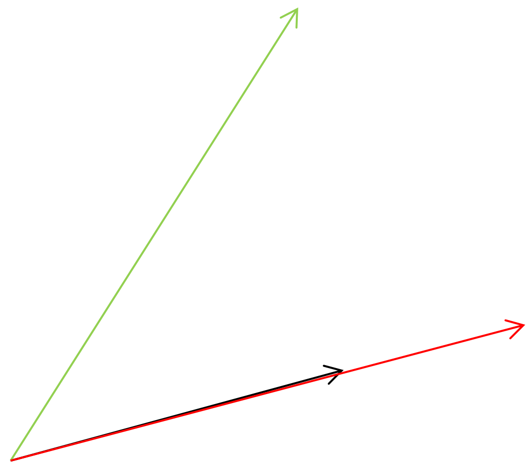
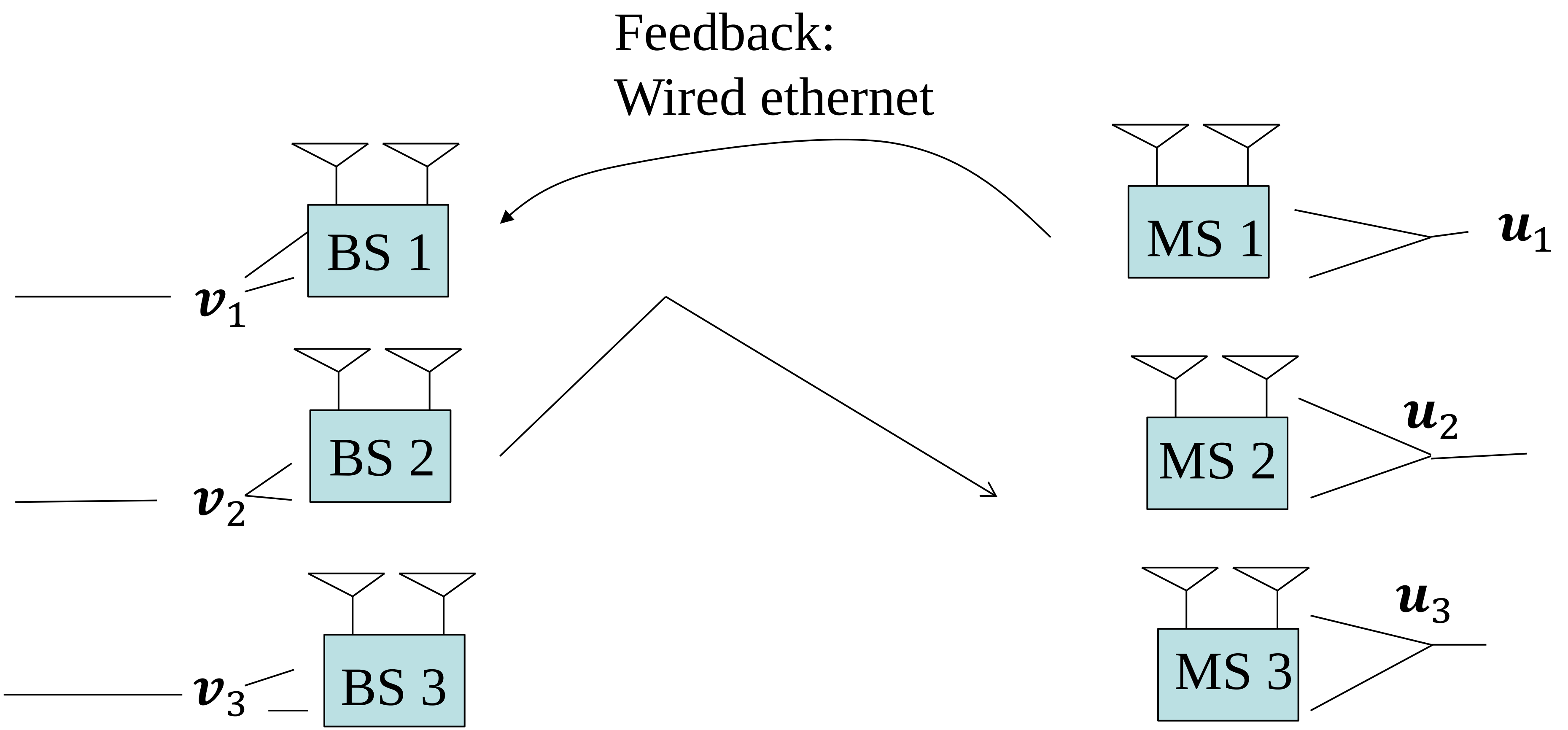
The ”alignment”



$$\mathbf{y} = \mathbf{w}^{\mathbf{H}}\left(\mathbf{x}_D + \mathbf{x}_1 + \ldots + \mathbf{x}_N\right) = \mathbf{w}^{\mathbf{H}}\mathbf{x}_D$$

Implementation IA



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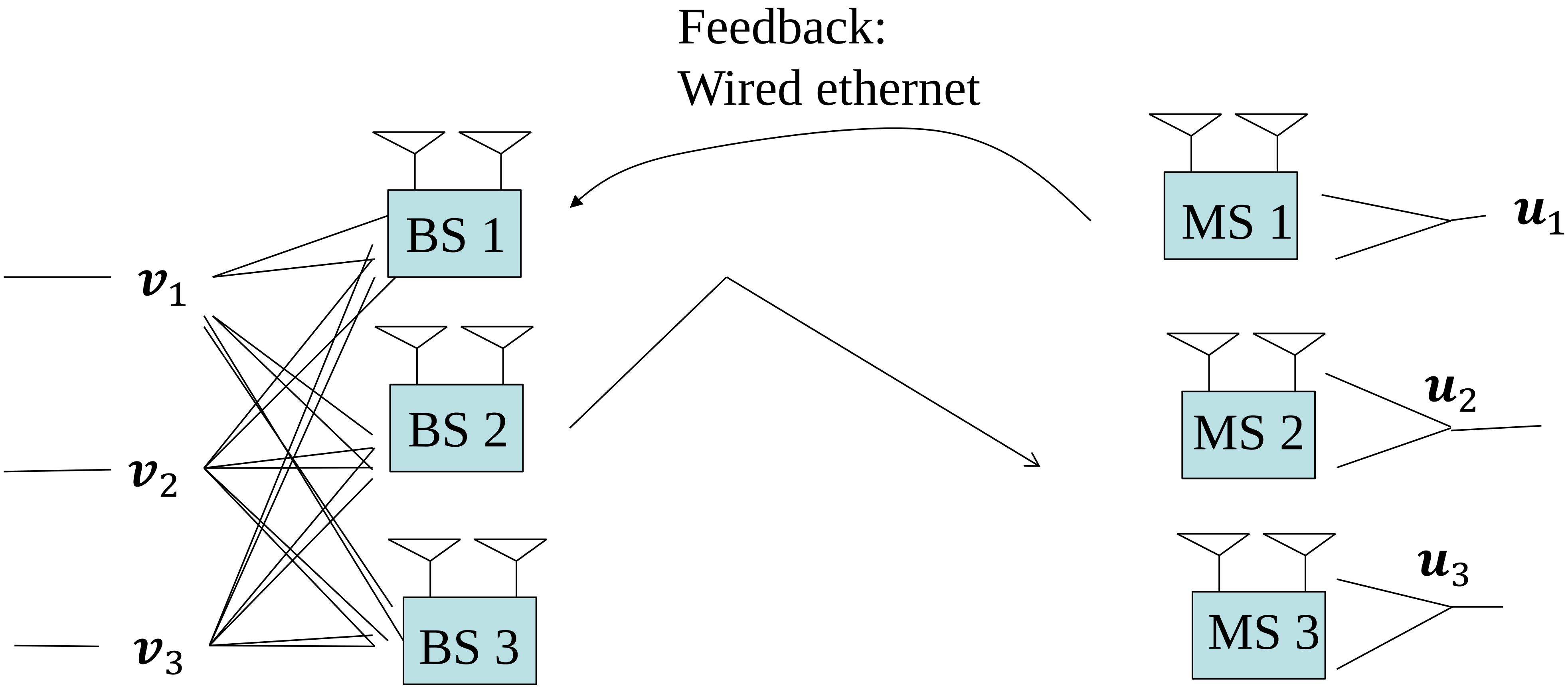
Implementation: CoMP



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Beamformer

$$\mathbf{SNIR}_k = \frac{\left|\mathbf{u}_k^*\mathbf{H}_{k,k}\mathbf{v}_k\right|^2}{\sum_{n\neq k}\left|\mathbf{u}_k^*\mathbf{H}_{k,n}\mathbf{v}_n\right|^2 + \tilde{\sigma}^2}$$

“Approaching the Capacity of Wireless Networks through Distributed Interference Alignment", by Krishna Gomadam, Viveck R. Cadambe and Syed A. Jafar.

$$\tilde{\sigma}^2 = \max\left(\sigma_N^2, 0.001\sum_n\left|\mathbf{H}_{k,n}\right|^2\right)$$

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Beamformer initialization CoMP

$$\mathbf{H}_1 = \left[\mathbf{H}_{11}, \mathbf{H}_{12,} \mathbf{H}_{13}\right] = \mathbf{U}_1 \mathbf{S}_1 \mathbf{V}_1^H$$

$$\mathbf{H}_2 = \left[\mathbf{H}_{21}, \mathbf{H}_{22,} \mathbf{H}_{23}\right] = \mathbf{U}_2 \mathbf{S}_2 \mathbf{V}_2^H$$

$$\mathbf{H}_3 = \left[\mathbf{H}_{31}, \mathbf{H}_{32,} \mathbf{H}_{33}\right] = \mathbf{U}_3 \mathbf{S}_3 \mathbf{V}_3^H$$

$$\tilde{\mathbf{V}} = \left[\mathbf{V}_1(:,1) \quad \mathbf{V}_2(:,1) \quad \mathbf{V}_3(:,1)\right]$$

$$\mathbf{W} = \tilde{\mathbf{V}}\left(\tilde{\mathbf{V}}^H \tilde{\mathbf{V}}\right)^{-1}$$

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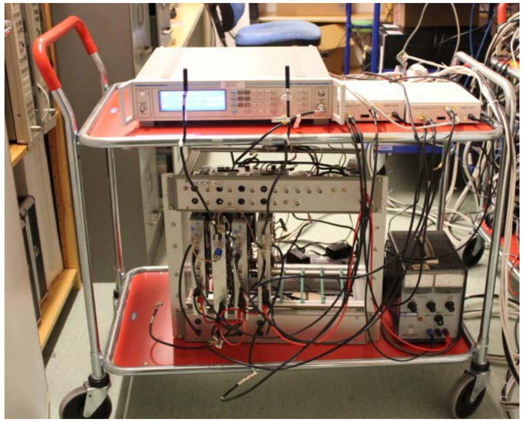
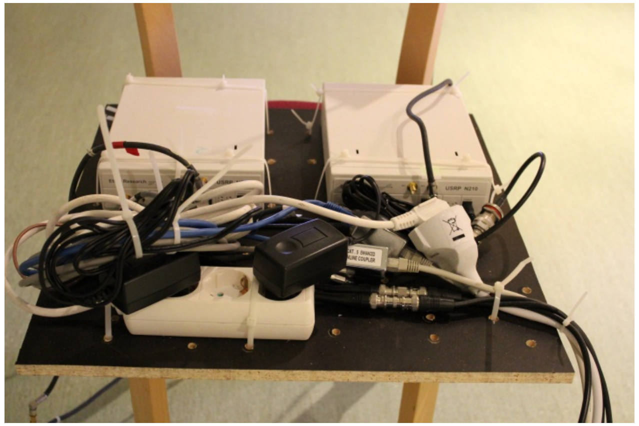
The testbed

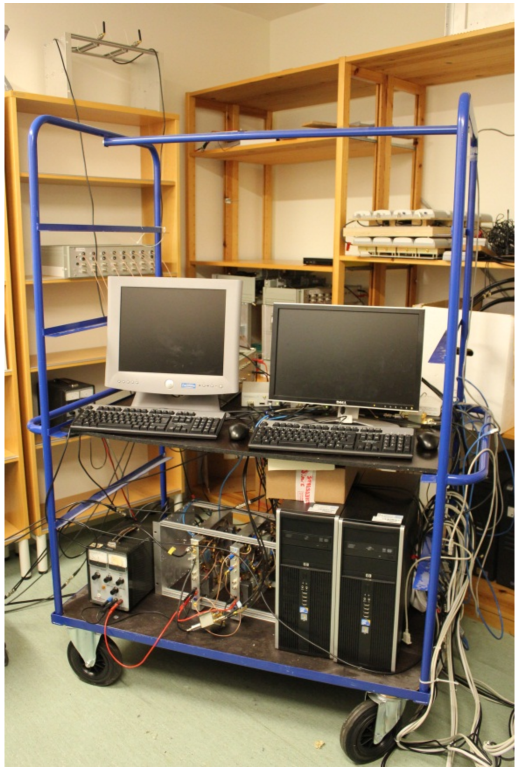
3MS



10m

3BS





10m

P=10dBm
NF=10-11dB

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IEEE 802.11ac feedback

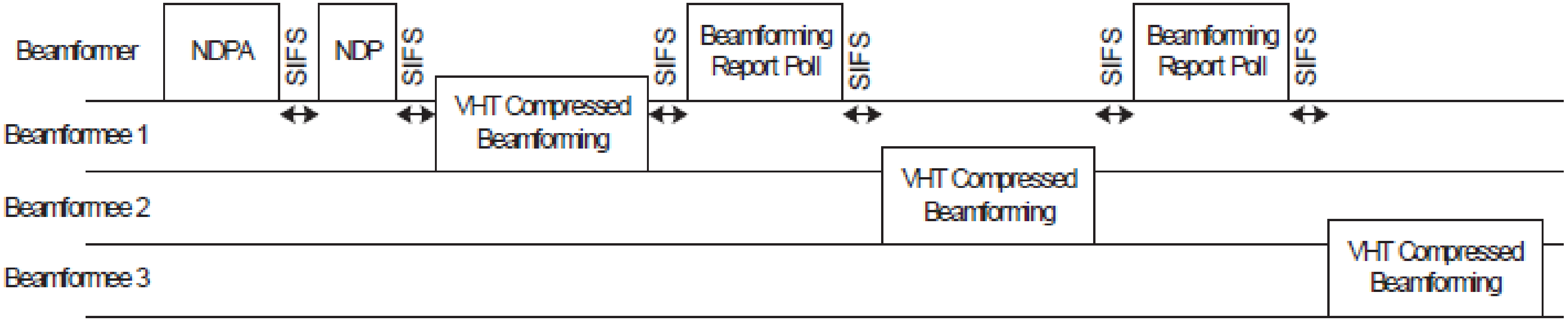

Figure 9-41b—Sounding protocol with more than one beamformee

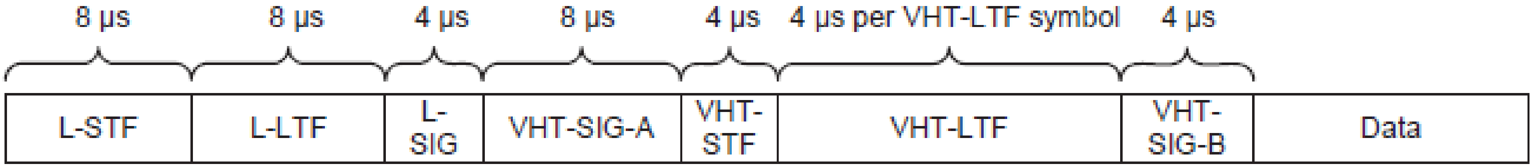

Figure 22-2—VHT PPDU format

Training symbols
One per antenna

IEEE 802.11ac feedback, contd.

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$$\mathbf{H} = \mathbf{U}\,\mathbf{S}\,\mathbf{V}^{H}$$

$$V = \left[\prod_{i=1}^{\min(N_c,\, N_r - 1)} \left[D_i\left(1_{i-1}\, e^{j\phi_{i,i}}, \ldots, e^{j\phi_{N_r-1,i}}, 1\right) \prod_{l=i+1}^{N_r} G_l^T\left(\psi_{l,i}\right) \right]\right] \tilde{I}_{N_r \times N_c}$$

Number of phis and psis : NcNr-Nc^2/-Nc/2

Range $0, 2\pi$ Range $0, \pi/2$

Quantization bits =7 or 9 Quantization bits 5 or 7

The whole 6x2 matrix is treated by the three MSs.

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Frequency granularity

Channel Width	*Ng*	*Ns*	Subcarriers for which Compressed Feedback Beamforming Matrix subfield is sent: *scidx*(0), *scidx*(1), …, *scidx*(*Ns*-1)
20 MHz	1	52	-28, -27, -26, -25, -24, -23, -22, -20, -19, -18, -17, -16, -15, -14, -13, -12, -11, -10, -9, -8, -6, -5, -4, -3, -2, -1, 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28 NOTE—Pilot subcarriers (±21, ±7) and DC subcarrier (0) are skipped
	2	30	-28, -26, -24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, -1, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28
	4	16	-28, -24, -20, -16, -12, -8, -4, -1, 1, 4, 8, 12, 16, 20, 24, 28

Our implementation:

14MHz	1	38	-19, -18, -17, -16, -15, -14, -13, -12, -11, -10, -9, -8,-6, -5, -4, -3, -2, -1, 1, 2, 3, 4, 5, 6, 8, 9, 10, 11,12, 13, 14, 15, 16, 17, 18, 19
	2	20	-18, -16, -14, -12, -10, -8, -6, -4, -2, -1, 1, 2, 4, 6,8, 10, 12, 14, 16, 18
	4	8	-12, -8, -4, -1, 1, 4,8, 12
	8	6	-16, -8, -1, 1, 8, 16
	16	4	-16,-1,1,16

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SNR feedback

$$\Delta SNR_{k,i} = \begin{cases} min(round(10\log_{10}\left(\frac{\|H_k V_{k,i}\|^2}{N}\right) - \overline{SNR_i}), 7), & \text{if } 10\log_{10}\frac{\|H_k V_{k,i}\|^2}{N} \geq \overline{SNR_i} \\ min(round(10\log_{10}\left(\frac{\|H_k V_{k,i}\|^2}{N}\right) - \overline{SNR_i}), -8), & \text{otherwise} \end{cases}$$

Channel Width	Ng	Ns'	Subcarriers for which the Delta SNR subfield is sent: *scidx*(0), *scidx*(1), … *scidx*(*Ns'*-1)
20 MHz	1	30	-28, -26, -24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, -1, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28
	2	16	-28, -24, -20, -16, -12, -8, -4, -1, 1, 4, 8, 12, 16, 20, 24, 28
	4	10	-28, -20, -12, -4, -1, 1, 4, 12, 20, 28
14MHz	1	20	-18, -16, -14, -12, -10, -8, -6, -4, -2, -1, 1, 2, 4, 6,8, 10, 12,14, 16, 18";
	2	10	-16, -12, -8, -4, -1, 1, 4, 8, 12, 16
	4	8	12, -8, -4, -1, 1, 4, 8,12
	8	4	-8, -1, 1, 8
	16	2	-16,16

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Interpolate between subcarriers

Reuse **V** on adjacent subcarriers.

Interpolate SNR values

Reconstruct H as:

H=diag(SNR0,SNR1)*V.

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Overhead

- The three short frames ≈ 2*60μs+num_users*60μs
- Gaps=2 SIFS + num_users SIFS
- Number of feedback bits per V matrix= (NcNr-Nc^2/-Nc)(7+9)
- Number of feedback for SNR num_users*8*SNRs*Nr

Feedback time in our case≈ 350μs+1065μs/(Ng*R)
Ng=4, R=2 => 500μs
With update interval : 20ms
=> Overhead 2.5%

Based on: *Improved MU-MIMO Performance for Future 802.11 Systems Using Differential Feedback*, Ron Porat

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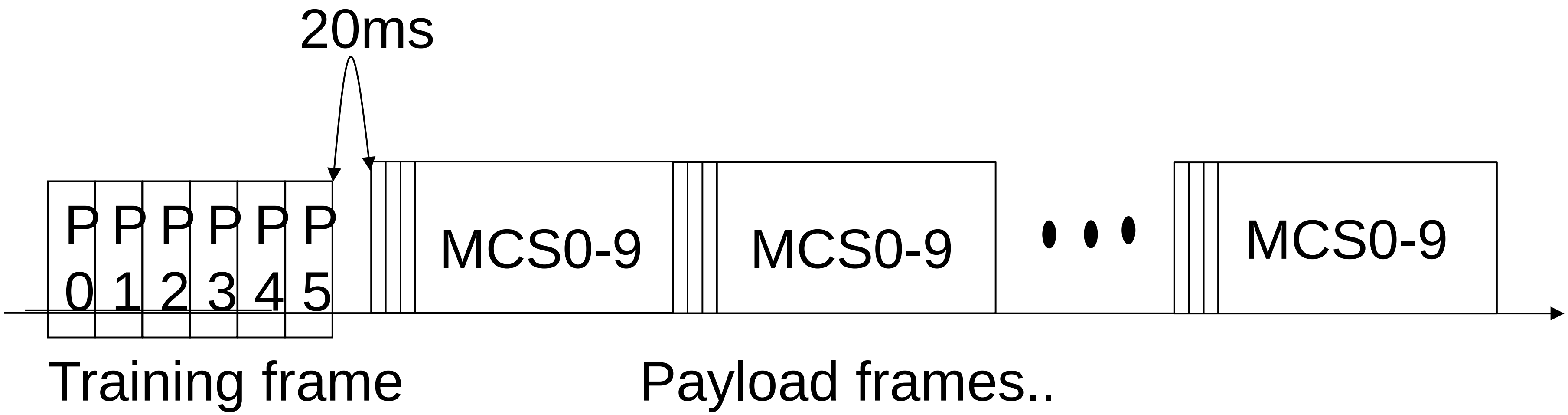
Our implementation

1. BS1 sends P0,P1
2. BS2 sends P2,P3
3. BS3 sends P4,P5
4. MS1-MS3 sends compressed V matrix to BS1.
5. BS1 un-compresses calculates all beamformes using max SINR on 38subcarriers.
6. Each BS sends beamformed frames.
7. MSs saves all data.
8. Post-processing of received signals.



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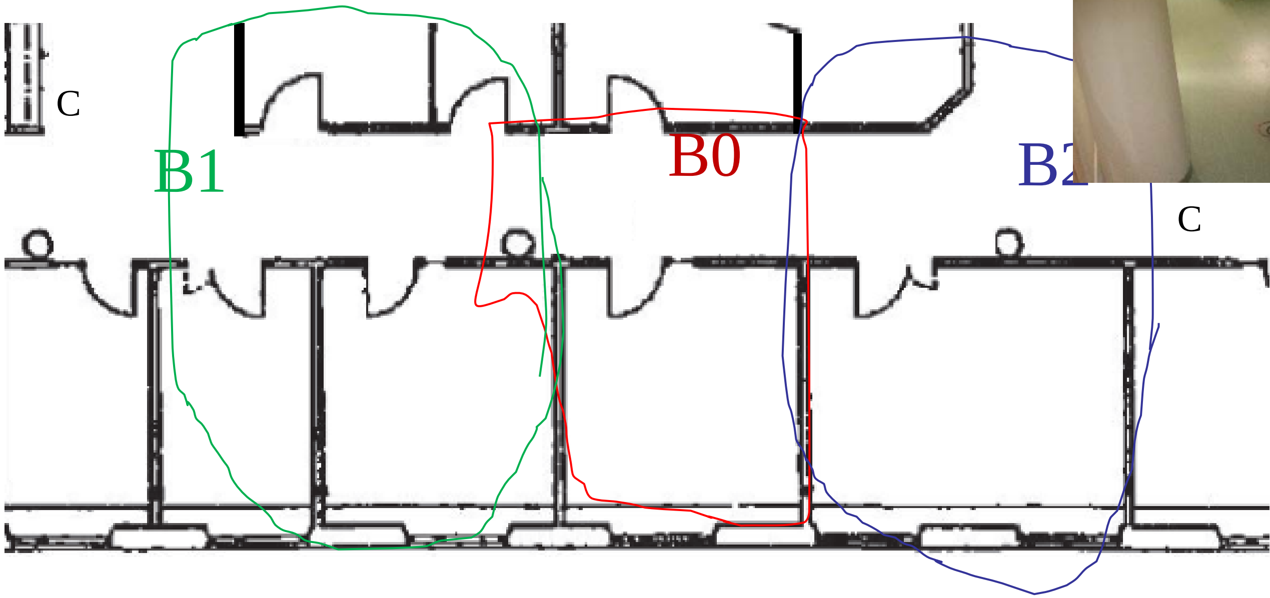
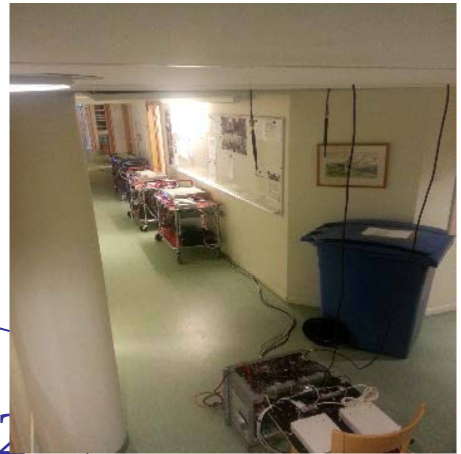
Measurement environment





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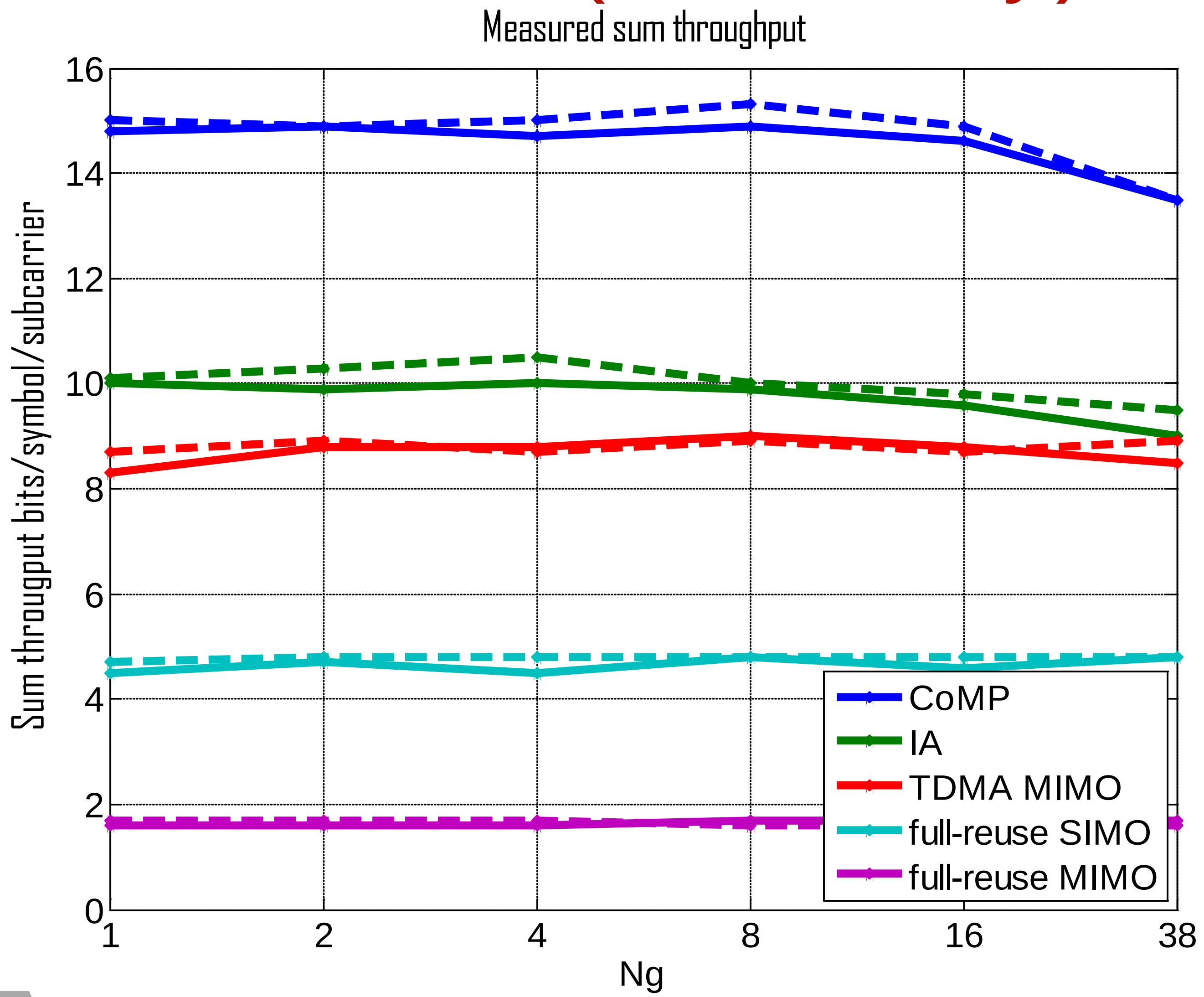
Results LoS (stationary)



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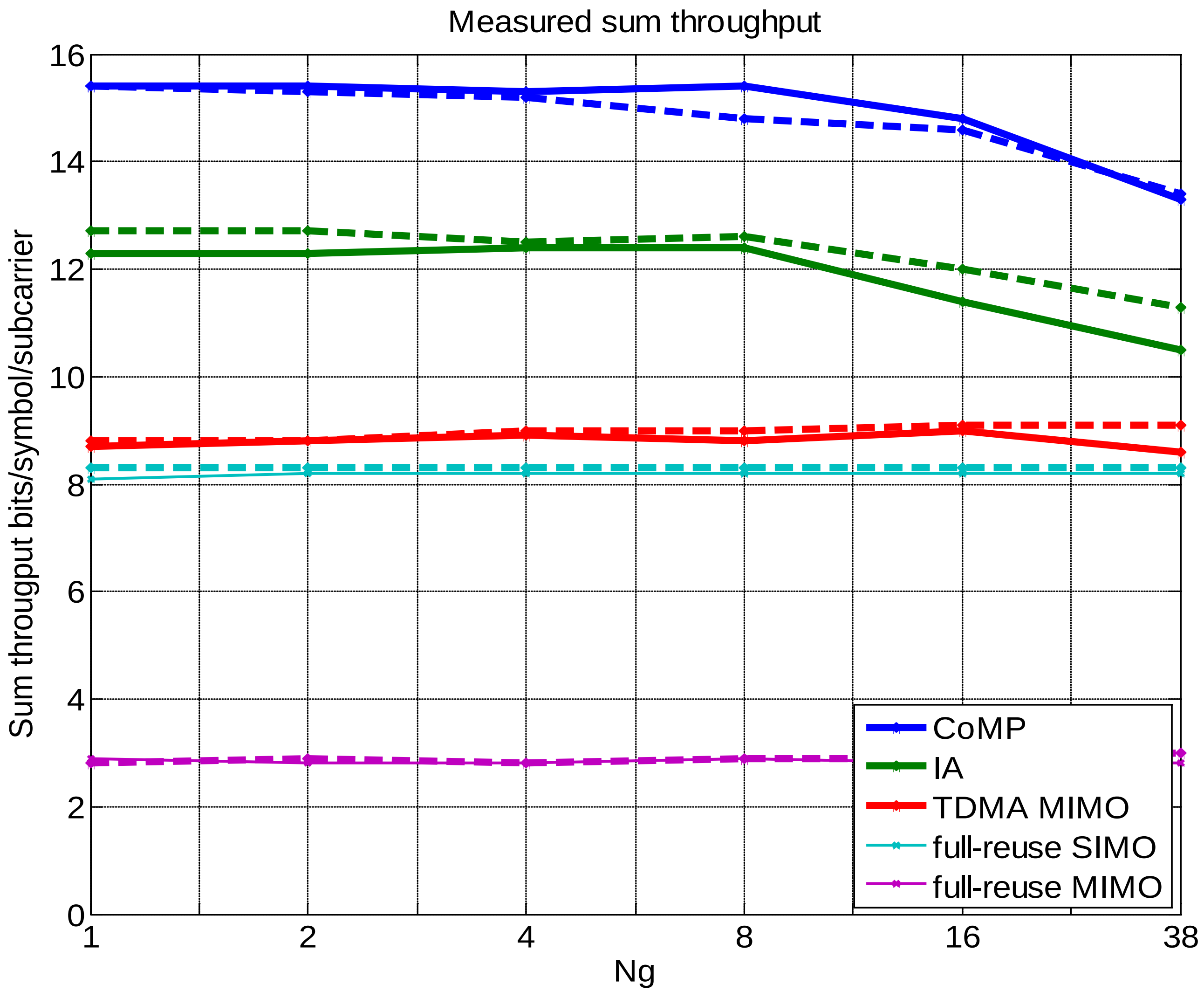
Results NLoS (stationary)



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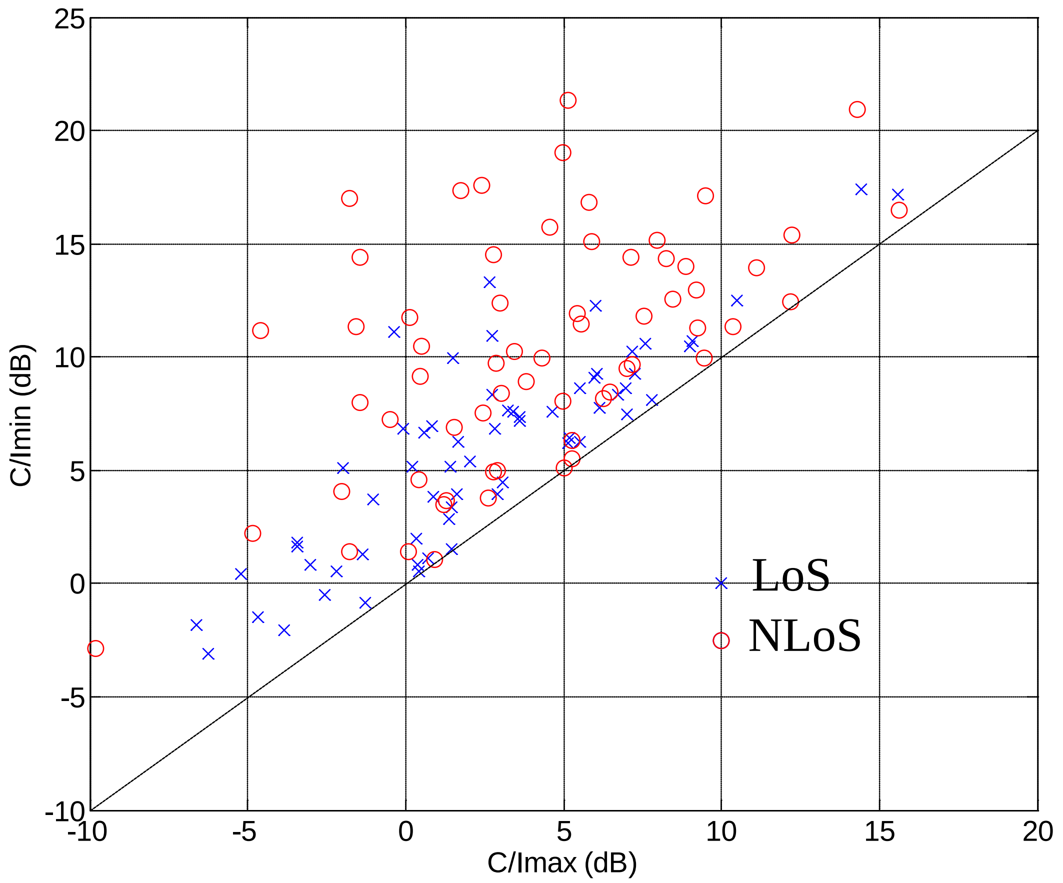
Why is NLoS better for IA?



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Time varying channels

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Time varying channels

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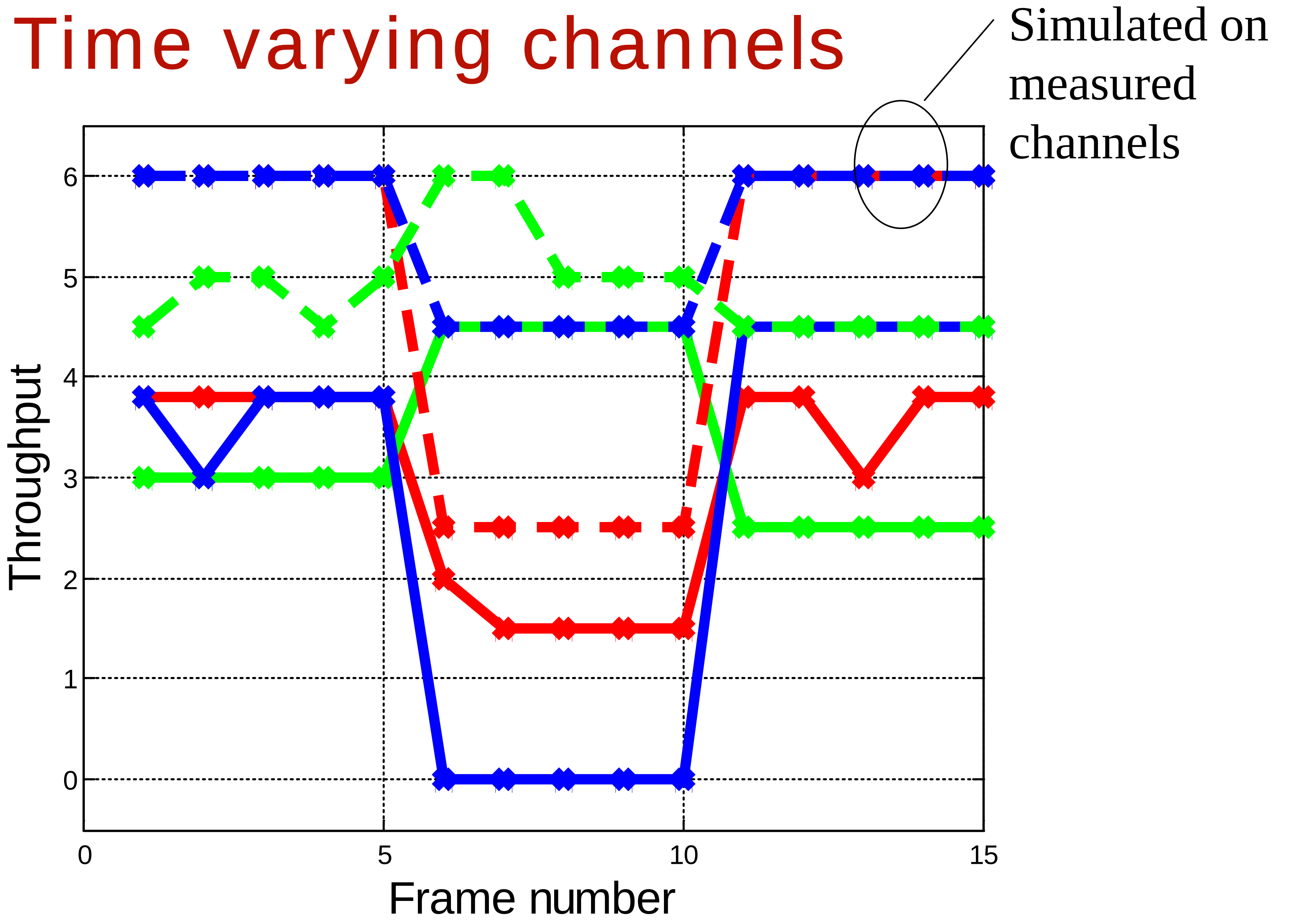
Time varying channels



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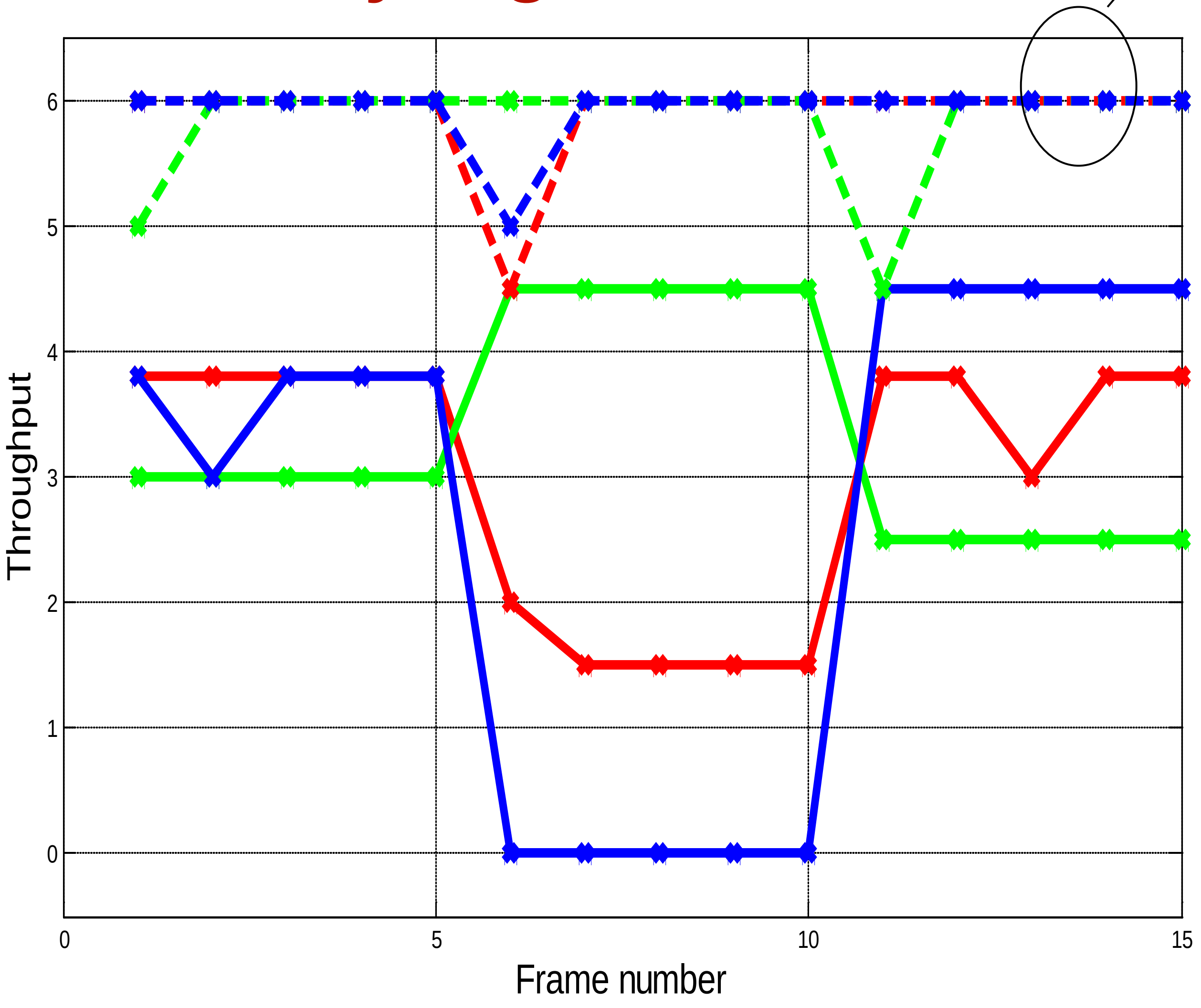
Time varying channels

0.5ms feedback delay



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Conclusion

- IA gives 25% sum throughput gain over SU MIMO on stationary channel (LoS and NLoS averaged)
- CoMP gives 71% gain over SU MIMO.
- All schemes limited by RF impairments.
- Geometry factor imortant for IA versus MIMO.
- Full reuse SIMO and MIMO worse than SU MIMO.
- Next step: analyzing measurements with time varying channels.

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Results versus EVM model

Scheme	Actual performance	Impairment model
IA	11.1	11.7
CoMP	15.2	17.3
SU MIMO	8.9	8.1
FR SIMO	6.5	6.2
FR SIMO	2.3	2.3