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Reduced Feedback Opportunistic and Layered Random Beamforming for MIMO-OFDMA Systems

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Outline

- Introduction

- Feedback Reduction Schemes for opportunistic and layered random beamforming

- Numerical and Simulation Results

- Conclusions and Future Work

Multi-user Diversity

- Multi-user Diversity is inherent in a multi-user wireless network, which it is likely to be at least one mobile station whose channel is near its peak at one time/frequency provided different mobile stations have independent fading channels.
- The benefit of multi-user diversity is exploited by tracking the channel information of mobile stations and prioritizing the ones with best current channel conditions to improve the overall system performance.
- Traditional beamforming requires full channel state information (CSI) to fully exploit the multi-user diversity and the feedback requirements are significant especially for multi-carrier systems.

Multi-user Diversity

- As the number of active mobile stations increases, probability that at least one will have a strong channel, eligible for transmission increases.

- Multi-user diversity works only in environments of high mobility and scatter.

- When no such conditions exist, Multi-user diversity fails to provide and throughput gains.

- Techniques to ensure that Multi-user diversity can provide throughput gains in slow fading environments and for a small number of users developed.

Opportunistic Beamforming (OB)

- Multiple antennas used at the Base Station (BS) to induce random channel fluctuations.

- Effectively transforming a slow fading channel into a fast fading Rayleigh channel.

- Increases the dynamic range of channel strength. Peaks on which mobile stations can be scheduled for transmission

Channel variation before and after opportunistic beamforming
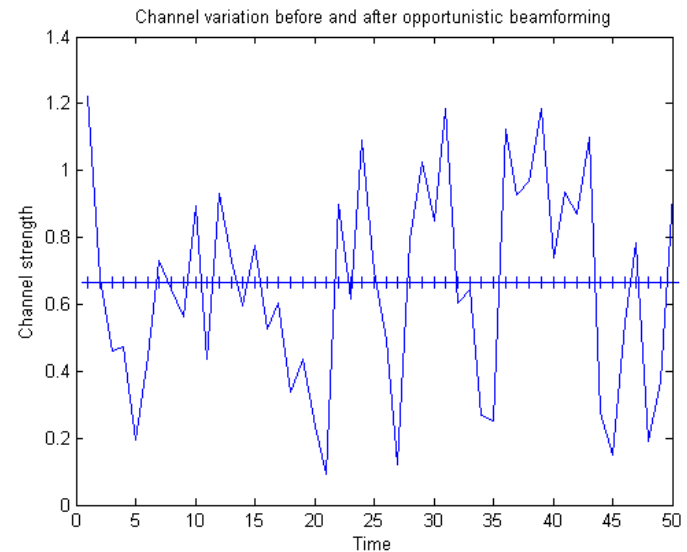
Random fluctuations induce peaks in channel strength, for which MS can be scheduled on

Opportunistic Beamforming (OB)

- Opportunistic Beamforming requires Channel State information (CSI) in the form of SNR, or requested rate Rk from each Mobile Station (MS) for every time slot.
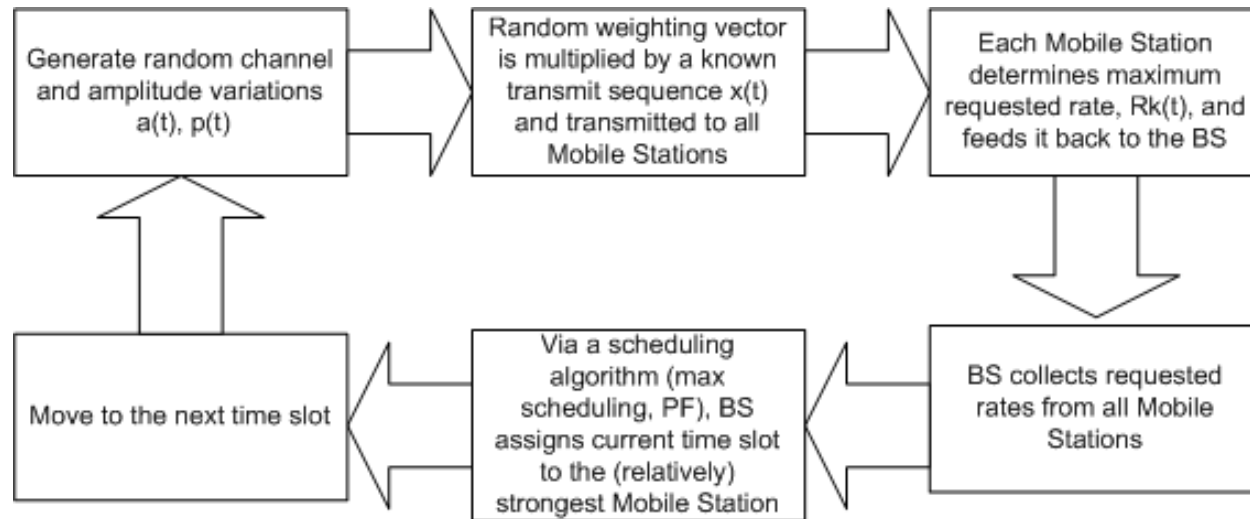
Multiple Weight Opportunistic Beamforming

- Multi-user diversity provides throughput benefits when in environments of high mobility and scatter.

- When no such channel conditions exist, random fluctuations are induced by multiple antennas at the BS.

- For a large number of active MSs, the probability that at least one MS will have a strong instantaneous channel gain, eligible for transmission increases.

- When the number of active MSs is small, can increase this probability by generating multiple channel realisations for each MS.

Multiple Weight Opportunistic Beamforming

- Multiple weighting vectors (Q) are transmitted from the BS to each MS. Each MS determines vector that returns highest instantaneous channel gain.

- Transmission of a weighting vector occupies a finite length (minislot) on the downlink slot (5-10%).

- Multiple vectors degrade maximum achievable throughput

- Maximum throughput: $$T_Q(t) = (L - \tau Q)\left(\max_{q=1,\ldots Q, k=1\ldots K} R_{q,k}(t)\right)$$

- *L:* downlink slot length

- *τ: minislot length*

- *Q: number of random weighting vectors*

Multiple Weight Opportunistic Beamforming

- Direct tradeoff between downlink slot overhead (associated with multiple weight transmission) and increase in diversity gains. (due to multiple channel realisations to each MS)

- An optimum number of random weighting vectors exist for a given number of active MSs, for a predefined minislot length.
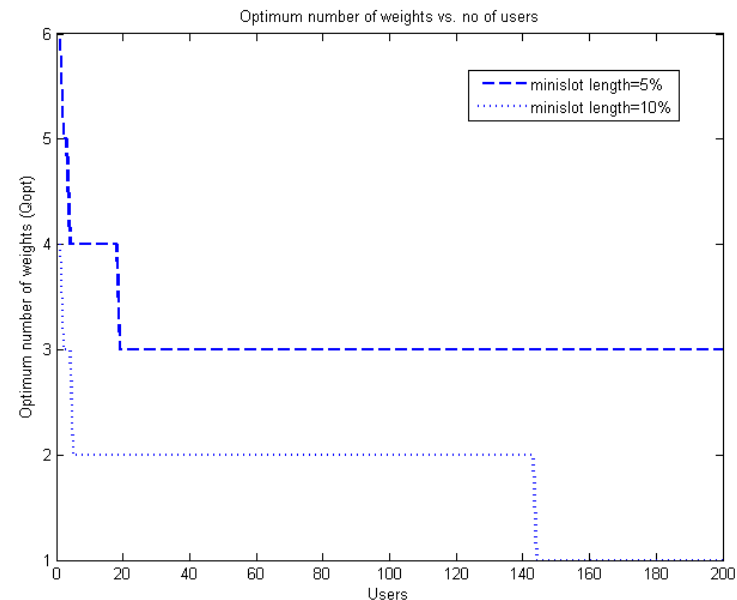
Scheduling in Opportunistic Beamforming with 1-bit feedback

- Conventional Opportunistic Beamforming scheduling requires CSI in the form of SNR from each MS for every time slot.

- Considerable feedback overhead, especially in OFDM systems where CSI is required for every subcarrier.

- Significant feedback reduction can be achieved by replacing SNR with 1-bit feedback per user.

- MS transmits a '1' if instantaneous channel gain is above a predefined threshold, indicating eligibility for transmission, else transmits '0' indicating ineligibility.

- BS randomly assigns an eligible MS for each slot.

Scheduling in Opportunistic Beamforming with 1-bit feedback

- Fairness of the system can be improved by scheduling users based on their previous utilisation.

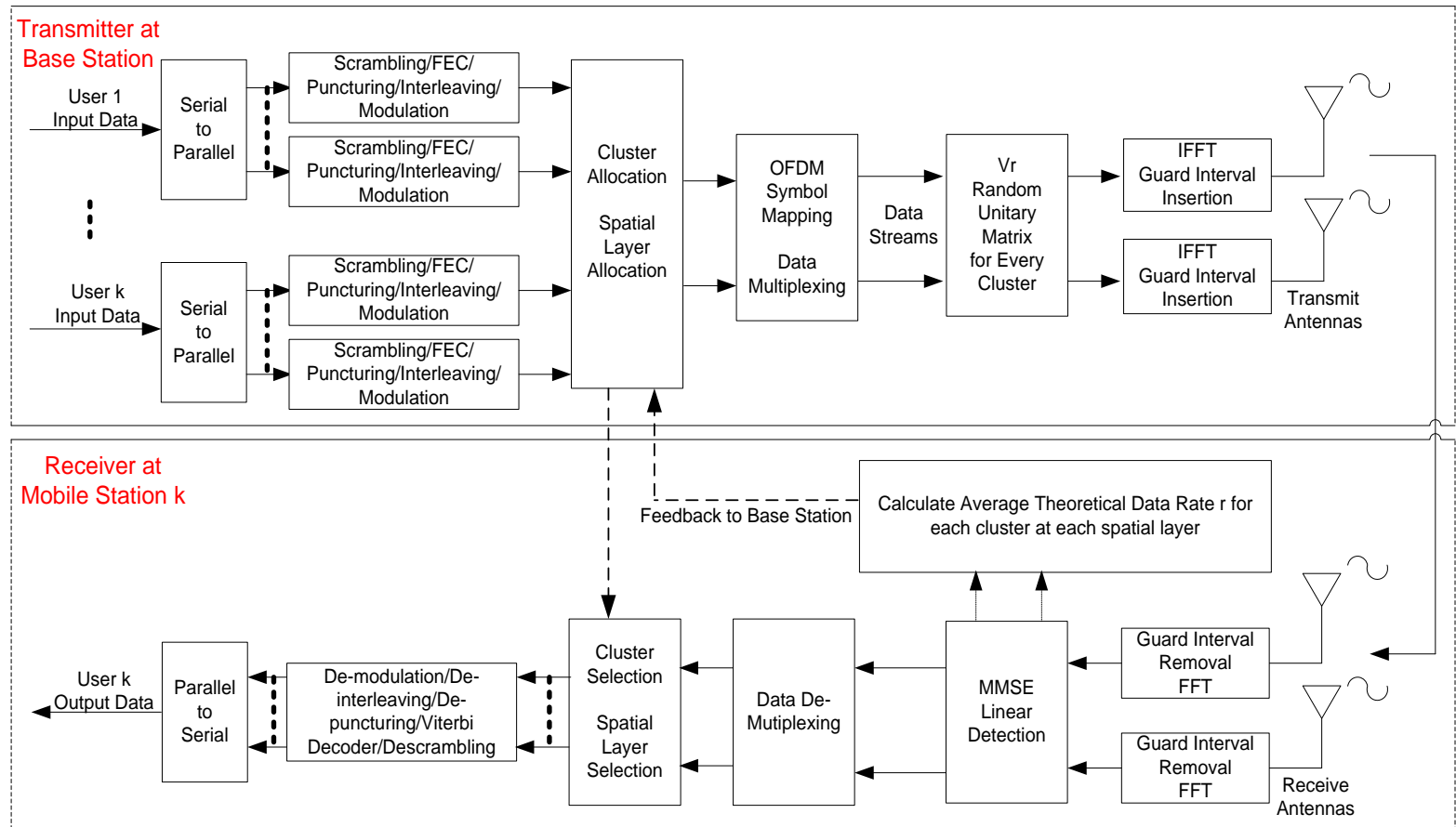- When no eligible users exist, system is in a stage of outage.

- Outage probability:

$$P_o = \left(1 - e^{-\gamma_{th}/\bar{\gamma}} \right)^K$$

- γ_{th} : *average channel gain*

- $\bar{\gamma}$: *threshold level*
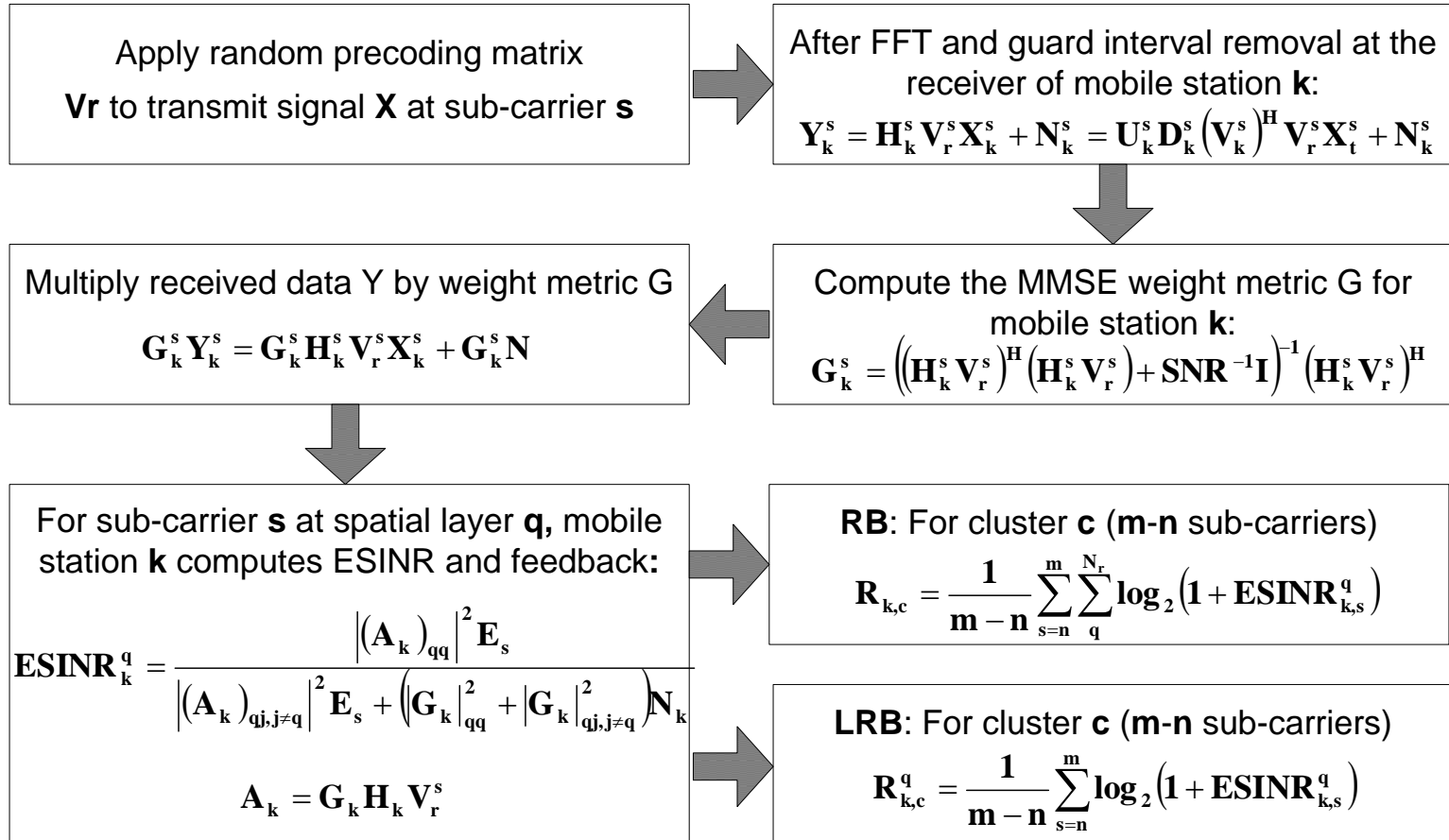
- *K : number of active users*

Layered Random Beamforming (LRB)

- a combination of the OB and SVD

- spatial multiplexing gain and spatial multi-user diversity gain.

- different spatial layers of the MIMO channels can be allocated to the same mobile station for random beamforming (RB) or to different mobile stations for LRB to achieve an additional layer spatial multi-user diversity gain

- MMSE based receiver, feedback ESINR based rate

- LRB-OFDMA achieves a further spectral multi-user diversity gain, but feedback on a sub-carrier basis results in a substantial overhead.

- Greedy algorithm selects the best mobile station for transmission at every spatial layer: $r_{k^*,c}^q = \max\left\{r_{1,c}^q, r_{2,c}^q, \cdots, r_{k,c}^q, \cdots\right\}$

RB-OFDM/A and LRB-OFDM/A

ESINR Based LRB-OFDMA

Apply random precoding matrix **Vr** to transmit signal **X** at sub-carrier **s**

After FFT and guard interval removal at the receiver of mobile station **k**:
$$\mathbf{Y_k^s} = \mathbf{H_k^s V_r^s X_k^s} + \mathbf{N_k^s} = \mathbf{U_k^s D_k^s \left(V_k^s\right)^H V_r^s X_t^s} + \mathbf{N_k^s}$$

Multiply received data Y by weight metric G
$$\mathbf{G_k^s Y_k^s} = \mathbf{G_k^s H_k^s V_r^s X_k^s} + \mathbf{G_k^s N}$$

Compute the MMSE weight metric G for mobile station **k**:
$$\mathbf{G_k^s} = \left(\left(\mathbf{H_k^s V_r^s}\right)^H \left(\mathbf{H_k^s V_r^s}\right) + \mathbf{SNR^{-1}I}\right)^{-1} \left(\mathbf{H_k^s V_r^s}\right)^H$$

For sub-carrier **s** at spatial layer **q,** mobile station **k** computes ESINR and feedback**:**
$$\mathbf{ESINR_k^q} = \frac{\left|\left(\mathbf{A_k}\right)_{qq}\right|^2 \mathbf{E_s}}{\left|\left(\mathbf{A_k}\right)_{qj,j\neq q}\right|^2 \mathbf{E_s} + \left(\left|\mathbf{G_k}\right|_{qq}^2 + \left|\mathbf{G_k}\right|_{qj,j\neq q}^2\right)\mathbf{N_k}}$$
$$\mathbf{A_k} = \mathbf{G_k H_k V_r^s}$$

RB: For cluster **c** (**m-n** sub-carriers)
$$\mathbf{R_{k,c}} = \frac{1}{\mathbf{m-n}} \sum_{s=n}^{m} \sum_{q}^{N_r} \mathbf{log_2}\left(1 + \mathbf{ESINR_{k,s}^q}\right)$$

LRB: For cluster **c** (**m-n** sub-carriers)
$$\mathbf{R_{k,c}^q} = \frac{1}{\mathbf{m-n}} \sum_{s=n}^{m} \mathbf{log_2}\left(1 + \mathbf{ESINR_{k,s}^q}\right)$$

Simulation Parameters and Channel Model

System Parameters

Operating Frequency	5 GHz
Bandwidth	100 MHz
FFT Size	1024
Useful Sub-carriers	768
Guard Interval Length	176
Sub-carrier Spacing	97.656 KHz
Useful Symbol Duration	10.24 μs
Total Symbol Duration	12.00 μs
Inner Channel Coding	Punctured 1/2 rate convolutional code, constraint length 7, $\{133,171\}_{octal}$
PHY Mode	Mode 1: BPSK with Coding Rate ½ Mode 6: 64QAM, Coding Rate ¾

Channels

Model	τ_{rms}	τ_{max}	T_s	Characteristics	Environment
A	50 ns	400 ns	10 ns	Rayleigh	Office NLOS
B	100 ns	740 ns	10 ns	Rayleigh	NLOS
C	150 ns	1060 ns	10 ns	Rayleigh	NLOS
E	250 ns	1770 ns	10 ns	Rayleigh	NLOS

LRB-OFDMA Simulation Performance
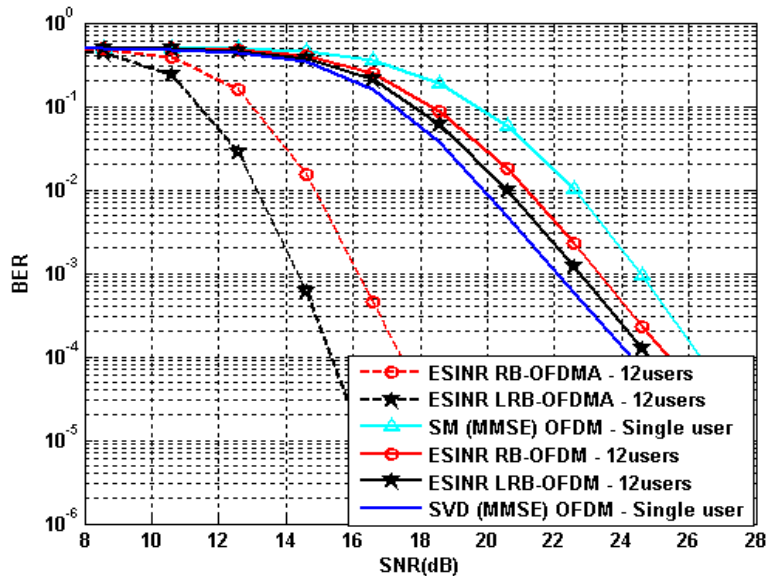
BER Performance of RB-OFDM/A, LRB-OFDM/A and SVD OFDM in Channel E (12 MSs in the Environment)
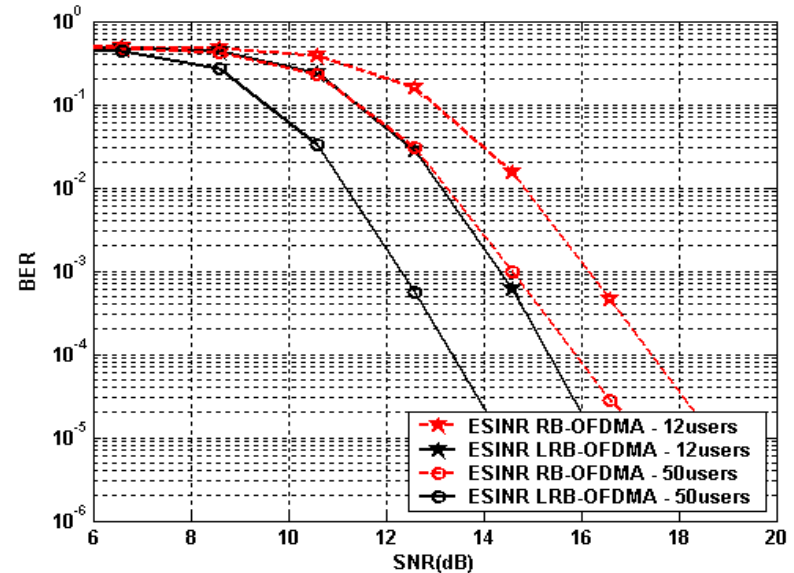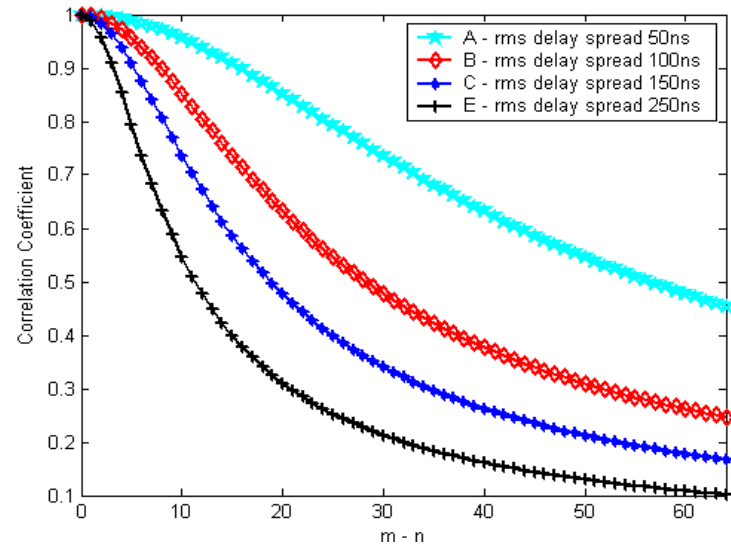
BER Performance of 12 and 50 MSs RB and LRB OFDMA (1 subcarrier per cluster) in Channel E

- LRB-OFDMA performs best due to its ability to effectively exploit both spectral and layer multi-user diversity gain.
- Higher spatial multi-user diversity gain can be exploited by LRB systems as number of MS increases

Exploiting Frequency Domain Correlation

- The frequency responses of the subcarriers in one cluster of an OFDMA symbol are correlated and the degree of correlation depends on the rms delay spread of the channel and the cluster bandwidth.

- The correlation between the effective channel gain of two sub-carriers (m and n) in a cluster is:

Correlation Coefficient between the Effective Channel Gains of Subcarriers in One Cluster in Different ESTI BRAN Channel Scenarios

$$r_{m,n} = \frac{1 - e^{-L\left(\frac{T_s}{\tau_{rms}} + j2\pi\frac{m-n}{N_s}\right)}}{\left(1 - e^{-\frac{LT_S}{\tau_{rms}}}\right)\left(1 + j2\pi\frac{m-n}{T_s N_s}\right)}$$

L guard interval

T_s Sampling period

τ_{rms} rms delay spread

N_s number of data sub-carriers

Exploiting Frequency Domain Correlation-Opportunistic Beamforming-Numerical Analysis

- Given that correlation of adjacent subcarriers within a cluster is high, treating a cluster as a single feedback unit, can significantly reduce feedback overhead with minor throughput degradations.

- Simulation performed for ETSI-BRAN Channel model-A for variable cluster size.
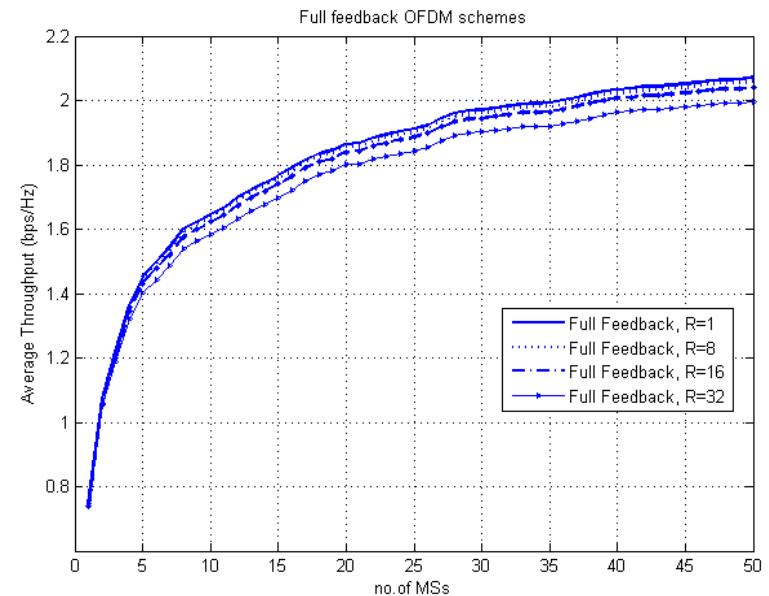
Exploiting Frequency Domain Correlation with 1-bit feedback- Numerical Analysis

- Scheduling with 1-bit feedback per MS extended to an OFDMA scheme. Effectively 1 bit required for each OFDMA feedback unit.

- Different cluster sizes can be treated as a single feedback unit with minor throughput degradation.
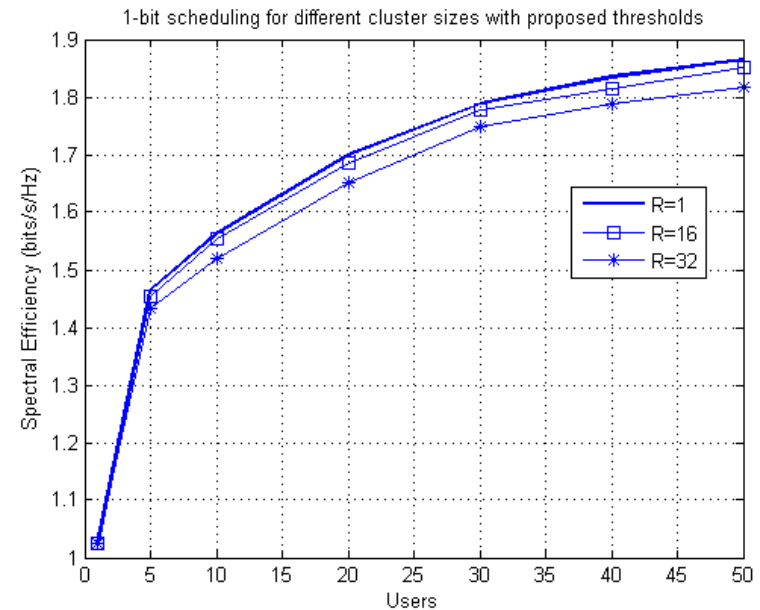
Opportunistic Beamforming
- General Numerical Analysis

- Average throughput results obtained for Multiple Weighting Vector, Single Weighting vector and 1-bit per cluster Opportunistic Beamforming.

- Same rate growth achieved in all schemes.

- Direct tradeoff between amount of CSI and throughput

Throughput of OFDM schemes with varying feedback requirements
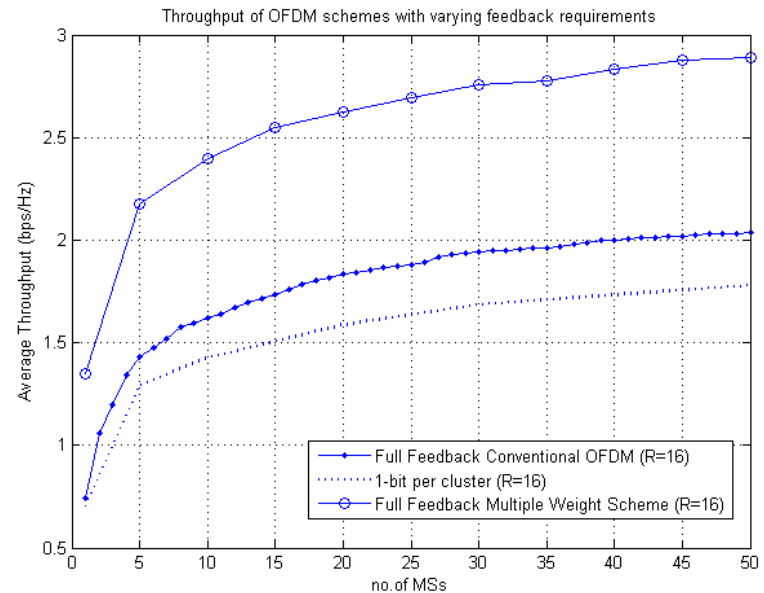
# Reduced Feedback LRB-OFDMA - Numerical Analysis
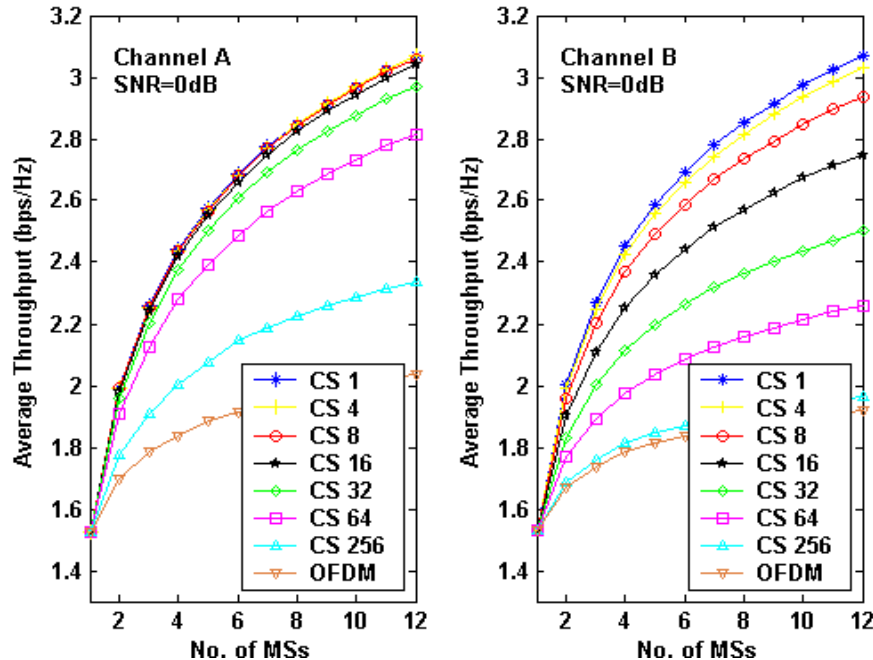
Average Numerical Throughput of LRB-OFDMA Employing Different Cluster Sizes at SNR=0dB in Channel A and E

- In channel A, the data rate performance of cluster size up to 16 is nearly identical to cluster size 1 due to the high frequency correlation of the subcarriers in the clusters

- Since channel E is more frequency selective, the correlation coefficient decreases much faster as the number of subcarriers per cluster increases.

- Compared to channel E, there is some frequency diversity that can be exploited when the cluster size reaches 256 in channel A.
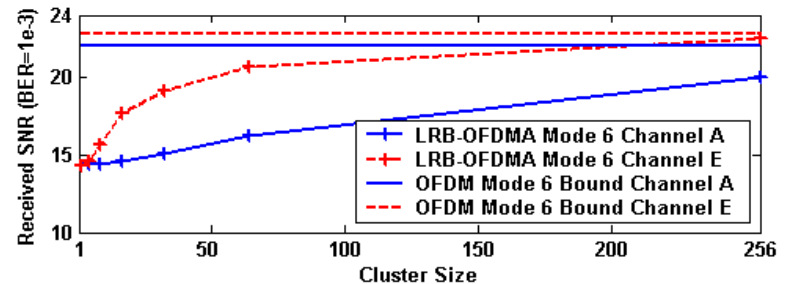
Reduced Feedback LRB-OFDMA
- Simulation Results
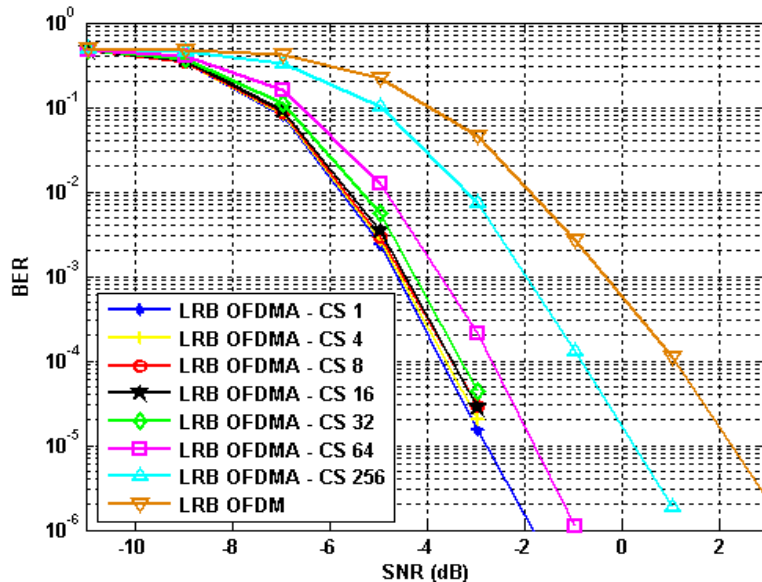
Mode 1 LRB-OFDMA Average BER Performance of
Different Cluster Sizes in Channel A
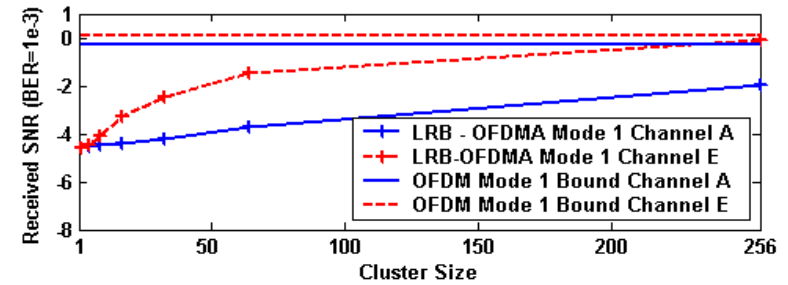
Mode 1 and 6 LRB-OFDMA Required SNR for Different Cluster
Sizes to Achieve Average BER 1e-3 in Channel A and E

- For small cluster sizes, system in channel E has a steeper slope than the same system in channel A due to higher frequency selectivity in channel E.

- The slope of channel E becomes flat when the cluster size is larger than 64. In contrast, there is a gradual increase in the required SNR until the cluster size reaches the maximum in channel A.

- Thank you for listening.

- Any questions, please?