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***EVALUATION OF THE CAPACITY OF
MULTIPLE-ACCESS MIMO SCHEMES
WITH FEEDBACK IN A SMALL OUTDOOR
CELL***

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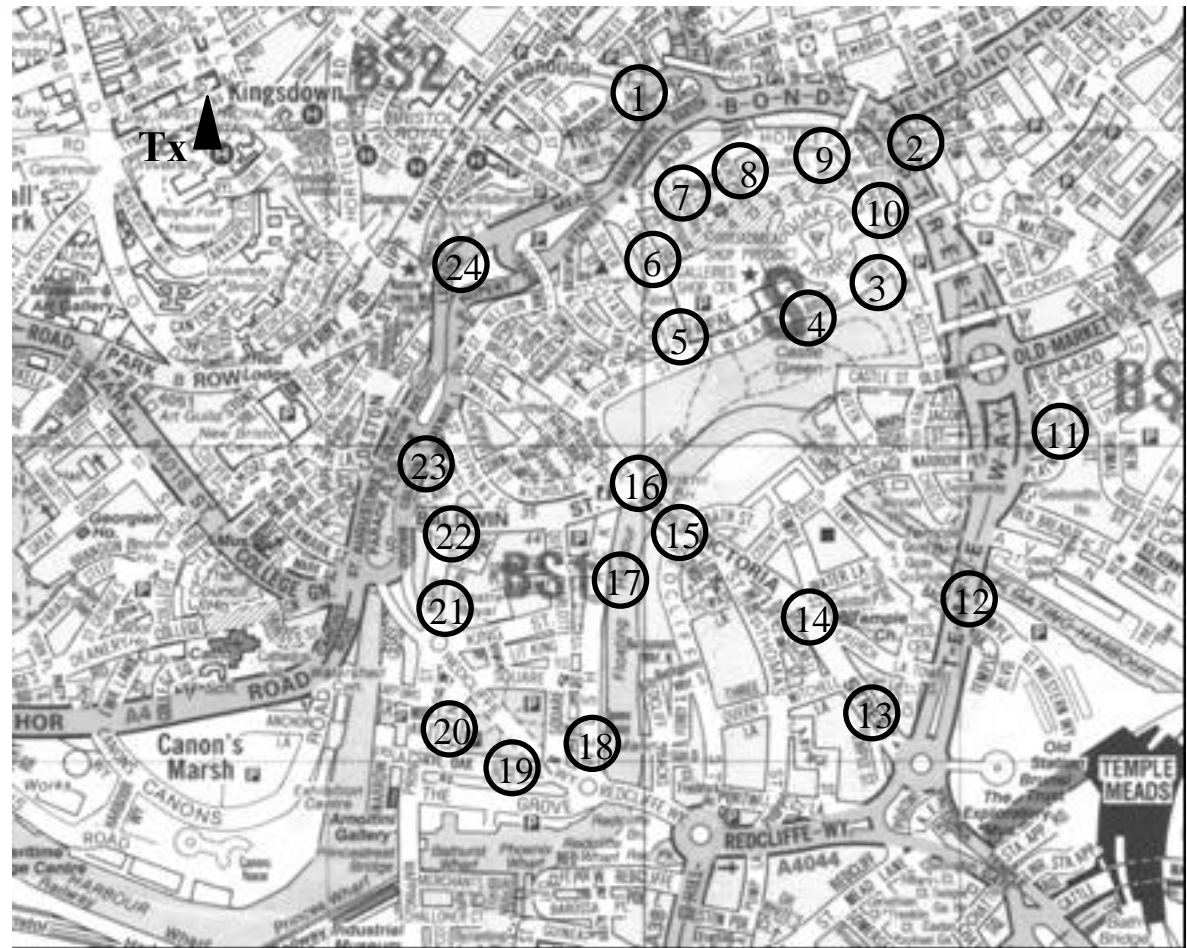
Introduction



- Use measured data from a highly-scattering environment to explore effect of waterfilling and 2 other transmit beamforming algorithms (e.g. by feedback of weights from BS)
 - Generalized waterfilling (Nash equilibrium)
 - Zero-forcing at TX
 - Successive zero-forcing at TX
- Examine how the algorithms could be used to provide differential QoS

Measurement setup

- 4 TX antennas
 - Two dual polarized 65° BW UMTS panel antennas
 - 20λ separation
 - Atop 30m-high building overlooking city centre
- 8 RX antennas
 - UCA, 8 monopoles
 - $\lambda/2$ radial spacing
- 24 positions, each 20.7s
 - 2x512 snapshots
 - 128 frequencies in 20MHz centred on 1.92GHz



Algorithms – Nash equilibrium

- Waterfilling – Nash Equilibrium – **non-cooperative** game
 - Waterfill pre-whitened channel $\mathbf{R}^{-1/2}\mathbf{H}$
 - \mathbf{R} is different from each user's perspective
 - One user waterfills their channel – affects all others
 - So next user waterfills current channel *etc...*
- Each user tends not to deviate from this profile since it would ultimately reduce their own capacity
- Requires knowledge of the current covariance for each user – either locally or centrally

Algorithms – Diagonalization

- AP has n_T antennas, j^{th} receiver has n_{R_j} antennas
- j^{th} receiver weights with \mathbf{R}_j , BS uses \mathbf{T}_j to communicate with it

$$\mathbf{y}_j = \mathbf{R}_j^\dagger \mathbf{H}_j \mathbf{T}_j \mathbf{s}_j + \mathbf{R}_j^\dagger \sum_{i \neq j} \mathbf{H}_j \mathbf{T}_i \mathbf{s}_i + \mathbf{w}_j$$

- **Block diagonalization** chooses \mathbf{T}_j to satisfy

$$\mathbf{R}_j^\dagger \mathbf{H}_j [\mathbf{T}_1 \quad \mathbf{T}_2 \quad \cdots \quad \mathbf{T}_L] = [\mathbf{0}_1 \quad \cdots \quad \mathbf{0}_{j-1} \quad \Lambda_j \quad \mathbf{0}_{j+1} \quad \cdots \quad \mathbf{0}_L]$$

- and \mathbf{R}_j to maximize end-to-end channel gain

- **Successive-diagonalization** chooses \mathbf{T}_j to satisfy

$$\mathbf{R}_j^\dagger \mathbf{H}_j [\mathbf{T}_1 \quad \mathbf{T}_2 \quad \cdots \quad \mathbf{T}_L] = [\mathbf{0}_1 \quad \cdots \quad \mathbf{0}_{j-1} \quad \Lambda_j \quad X \quad \cdots \quad X]$$

- Uses identity for \mathbf{R}_j , so is non-iterative – but order matters

'Transposing' the algorithms

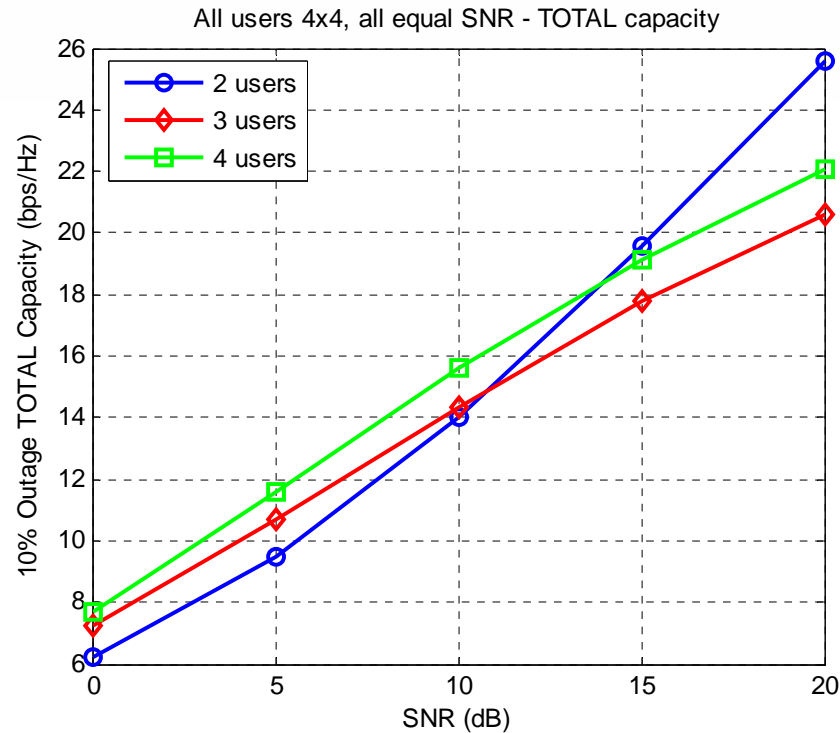
- Instead of having one, large BS communicating with several, smaller users, we will reverse the situation:
 - Construct a 'virtual' BS by aggregating the users
 - Actual BS appears as multiple users, separated by the different channels from the users
- Calculate weights the same way, but transpose everything
 - User j TX's with \mathbf{R}_j^* and is RX'd by filtering with \mathbf{T}_j^T
 - *i.e.* $(\mathbf{R}_j^\dagger \mathbf{H}_j \mathbf{T}_j)^T = \mathbf{T}_j^T \mathbf{H}_j^T \mathbf{R}_j^*$
- Limits on number of antennas and independent streams:

$$n_R \geq \sum_{j=1}^L N_j \quad \text{and} \quad n_{T_j} \geq N_j$$

Assumptions etc.

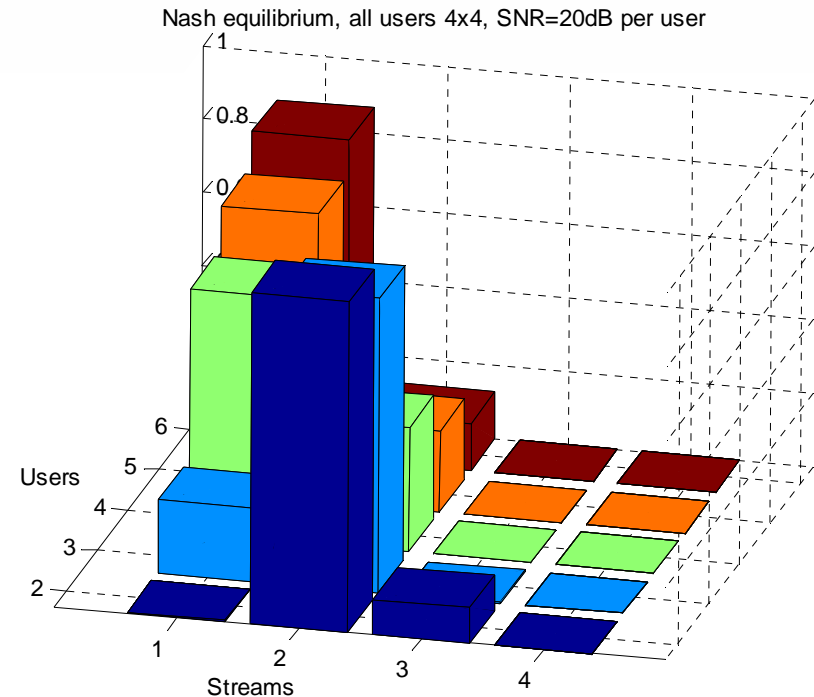
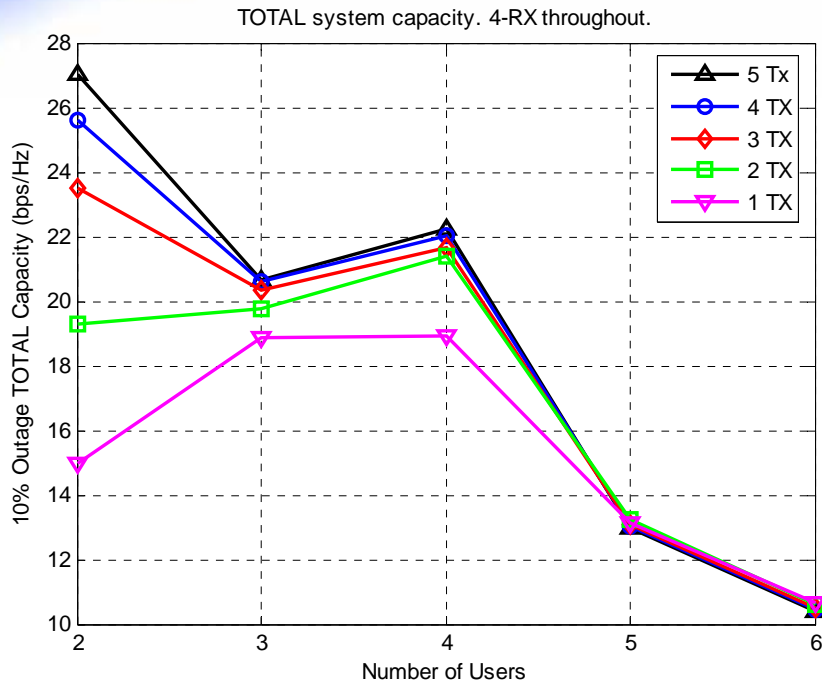
- Normalize channels so each user is RX'd at a specified SNR
- Will use same positions for interferers throughout
 - 'Wanted' user at position no. 24
 - Interferers at positions 5, 6, 7, 8 and 9 (i.e. 2-6 users)
- 4TX and 4RX antennas (except where noted)
- Quasi-static channel at each frequency snapshot
- Measure 10% outage capacity

Nash equilibrium I



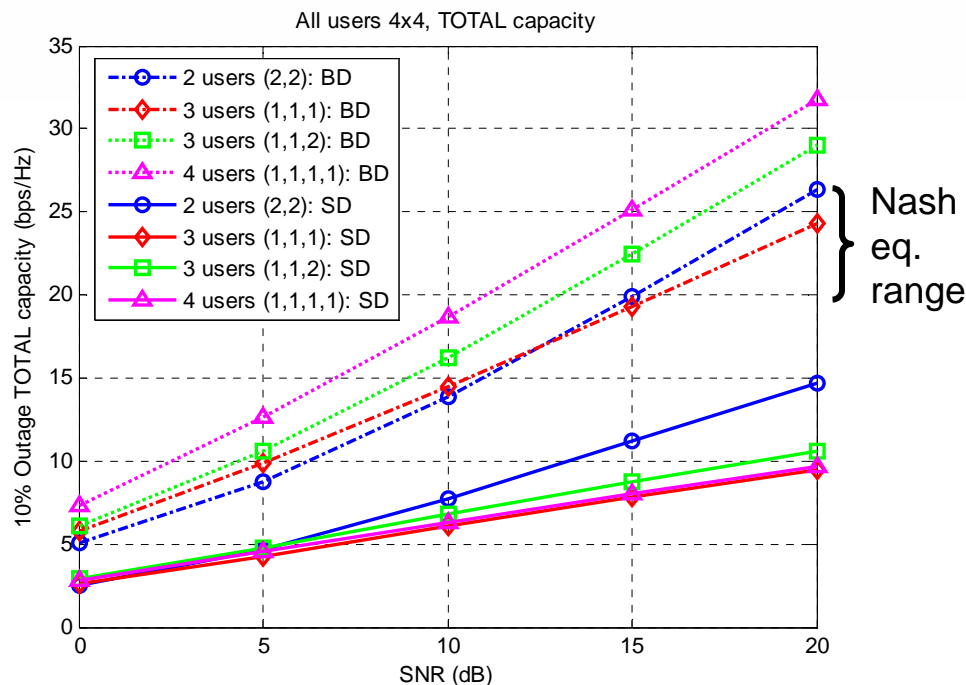
- 2-user system makes best use of higher SNR
- 4-user system yields higher capacity than 3-user system

Nash equilibrium II



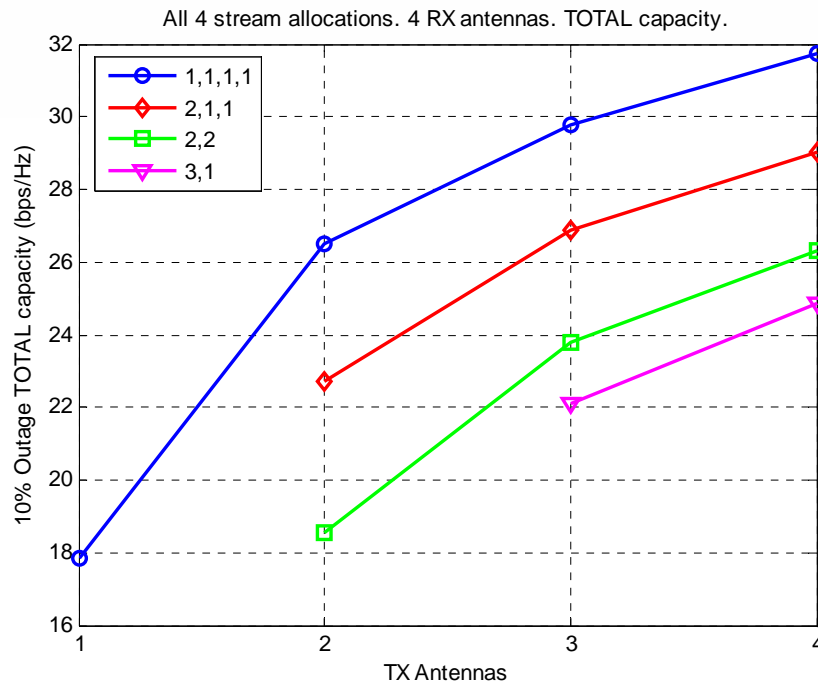
- Prefer to operate with a ‘few’ interferers if we must have >1
- With 2 users, can waterfill away from all interference by using only 2 streams each
- Abrupt change from 2 streams/user with 3 users to 1 stream/user with 4 users – again allows waterfilling away from interference

Diagonalization schemes – comparison



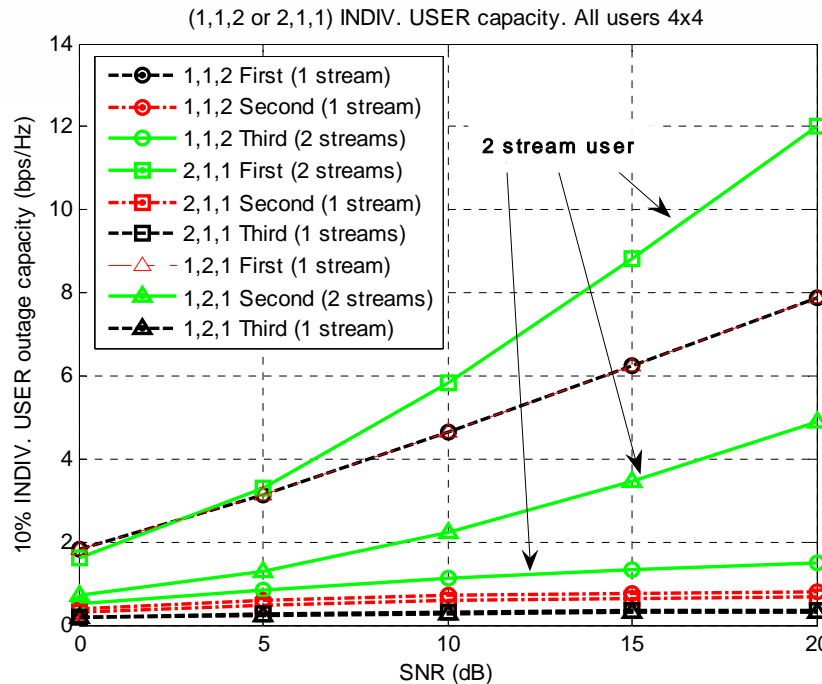
- Block-diagonalization up to 8.4bps/Hz better than Nash at 20dB
 - **Orthogonally** multiplexes users – Nash equilibrium does not
 - Gain over Nash small with 2 users – same stream distribution
- Successive-diagonalization much worse than either
 - Due to residual interference without any attempt to remove it
 - Better with fewer users at high SNR – less residual interference

Block diagonalization – stream allocation



- Distributing same number of streams among more users can give substantial improvements in total capacity
 - Waterfilling is able to choose best substreams across whole system rather than just one user – hence (1,1,1,1) is best
- Results in proportionally lower per-user capacity
 - Allows for diff-QoS if user is prepared to pay for lower overall rate

Successive-diagonalization - ordering



- 2-stream user's capacity varies dramatically depending on ordering
 - Cannot find 2 good subchannels when avoiding two 1-stream users
- 1-stream users have useful capacities *only* when others are orthogonal
- Not shown, but (2,1,1) better than (1,1,2) by only 2.8bps/Hz
 - Masks much wider per-user variations despite same stream nos.

Conclusions

- If seeking **maximum system capacity** use
 - Block-diagonalization with most users, fewest streams/user
 - Both Nash and block-diag. are much better than successive
- Nash equilibrium capacity can rise with more users, up to a point
- Distribution of available substreams among users is important
 - Exploit multi-user diversity to max. block-diag capacity
 - Ordering very important in successive diagonalization
 - Diagonalizations could offer differential QoS
 - (Does not apply to Nash equilibrium – approx. equal per-user)
- Nash and block-diag are iterative, but successive-diag is not
 - Nash equilibrium converges faster and more reliably
 - Successive-diag could be useful in rapidly changing channels

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