Nix, A. R., Webb, M. W., Hunukumbure, R. M. M., & Beach, M. A. (2005). Evaluation of the capacity of multiple-access MIMO schemes with feedback in a small outdoor cell. In IEE 6th International Conference on 3G and Beyond. (pp. 19 - 23). Institution of Electrical Engineers (IEE). 10.1049/cp:20050186

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

Matthew Webb, Mythri Hunukumbure, Mark Beach, Andrew Nix

IEE Conference on 3G and Beyond

London, 7th November 2005

University of Bristol
Centre for Communications Research

University of BRISTOL

Introduction

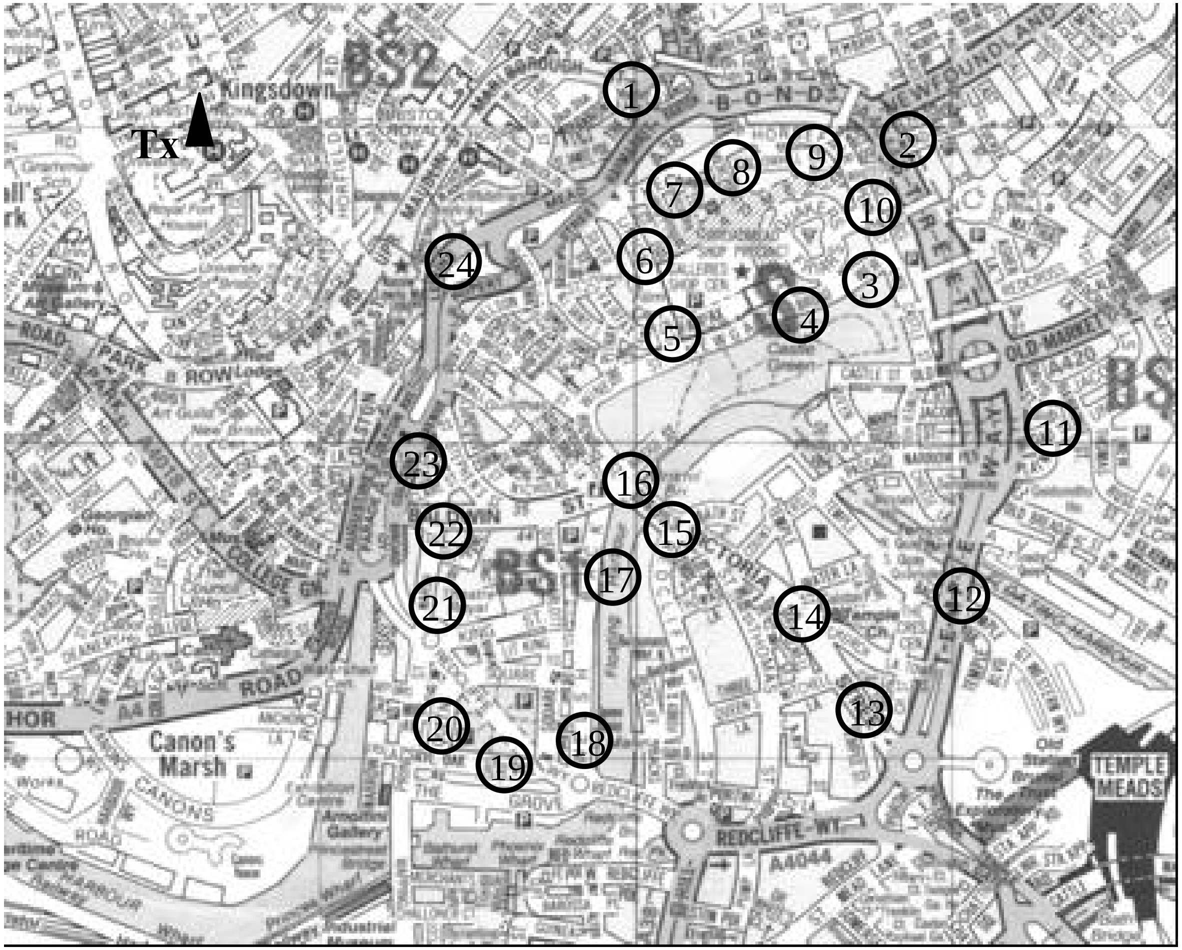
University of BRISTOL

- 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

University of BRISTOL

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



Algorithms – Nash equilibrium

University of BRISTOL

- 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

University of BRISTOL

- AP has n_T antennas, j^{th} receiver has n_{Rj} 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

$$\mathbf{R}_j^{\dagger}\mathbf{H}_j\begin{bmatrix}\mathbf{T}_1 & \mathbf{T}_2 & \cdots & \mathbf{T}_L\end{bmatrix} = \begin{bmatrix}\mathbf{0}_1 & \cdots & \mathbf{0}_{j-1} & \mathbf{\Lambda}_j & \mathbf{0}_{j+1} & \cdots & \mathbf{0}_L\end{bmatrix}$$

- and $\mathbf{R}_j$ to maximize end-to-end channel gain
- **Successive-diagonalization** chooses $\mathbf{T}_j$ to satisfy

$$\mathbf{R}_j^{\dagger}\mathbf{H}_j\begin{bmatrix}\mathbf{T}_1 & \mathbf{T}_2 & \cdots & \mathbf{T}_L\end{bmatrix} = \begin{bmatrix}\mathbf{0}_1 & \cdots & \mathbf{0}_{j-1} & \mathbf{\Lambda}_j & X & \cdots & X\end{bmatrix}$$

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

'Transposing' the algorithms

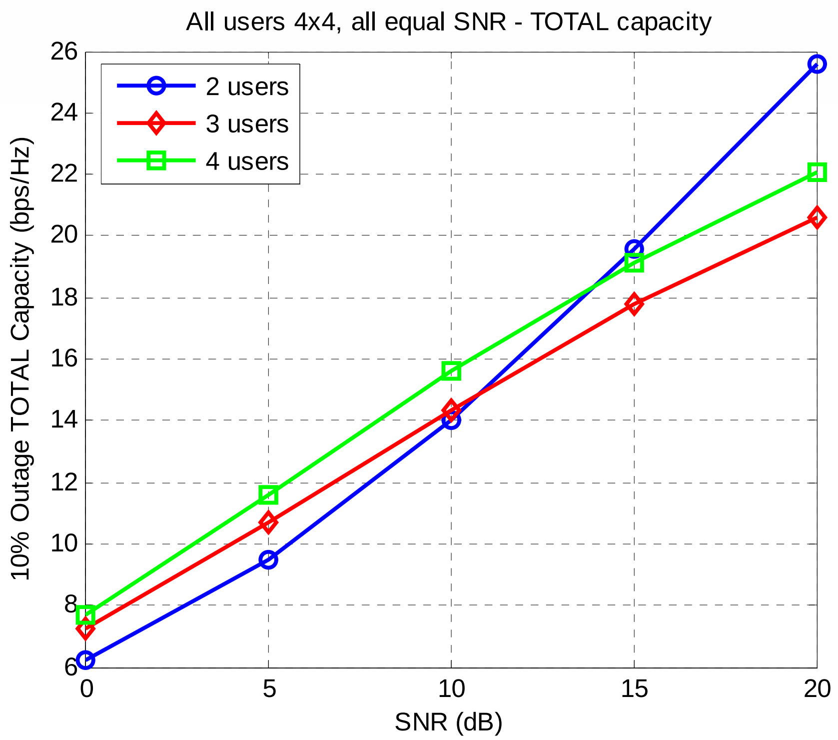
- Instead of having one, large BS communicating with several, smaller users, we will reverse the situation:
  - Construct a 'virtual' BS by aggregating the users
  - Actual BS appears as multiple users, separated by the different channels from the users
- Calculate weights the same way, but transpose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

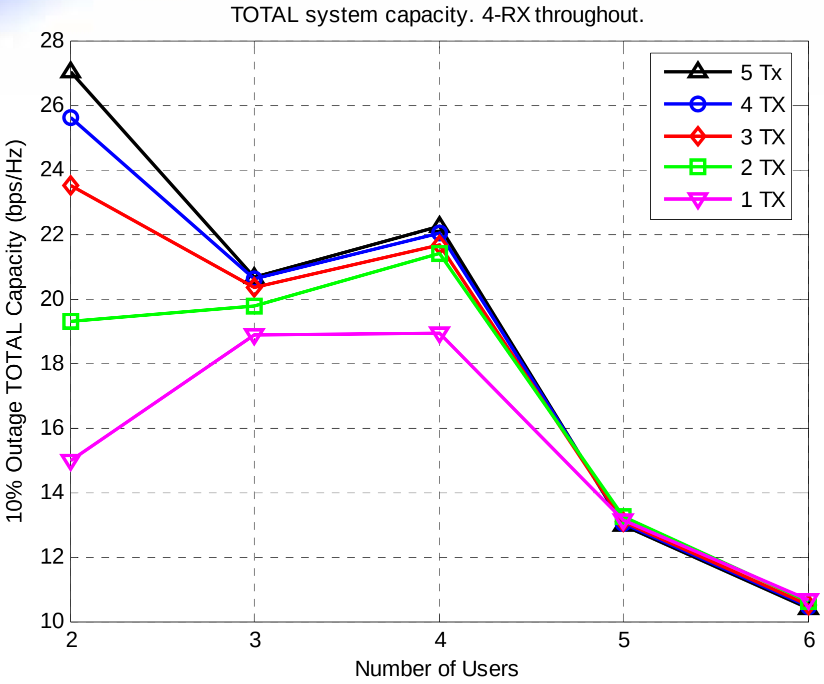
- Normalize channels so each user is RX'd at a specified SNR
- Will use same positions for interferers throughout
  - 'Wanted' user at position no. 24
  - Interferers at positions 5, 6, 7, 8 and 9 (i.e. 2-6 users)
- 4TX and 4RX antennas (except where noted)
- Quasi-static channel at each frequency snapshot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

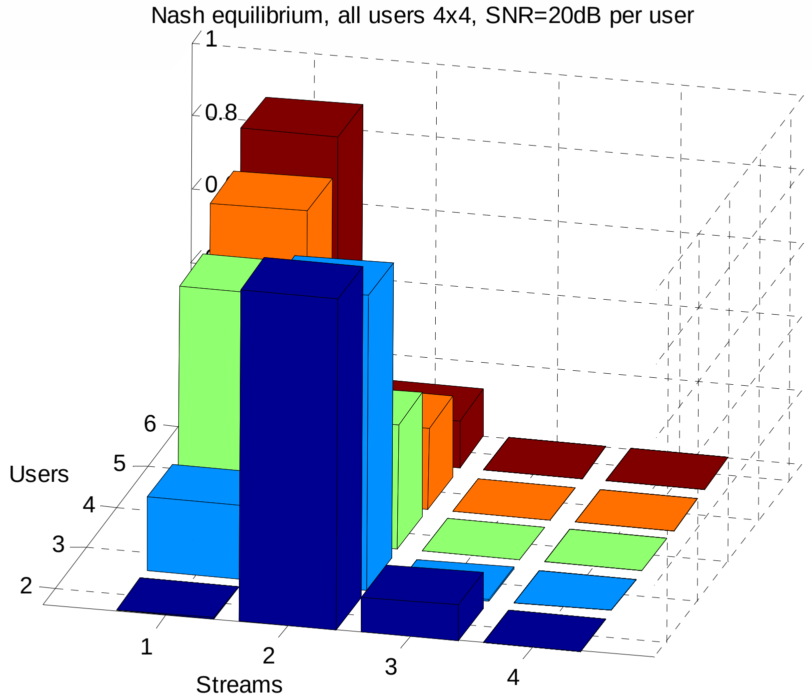
Nash equilibrium I



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

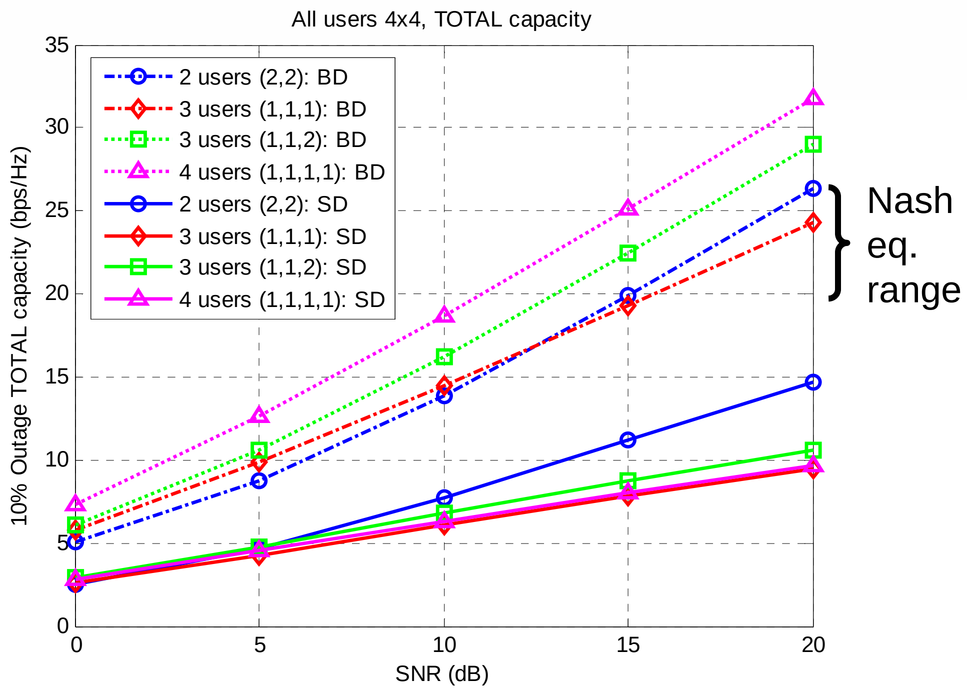
Nash equilibrium II





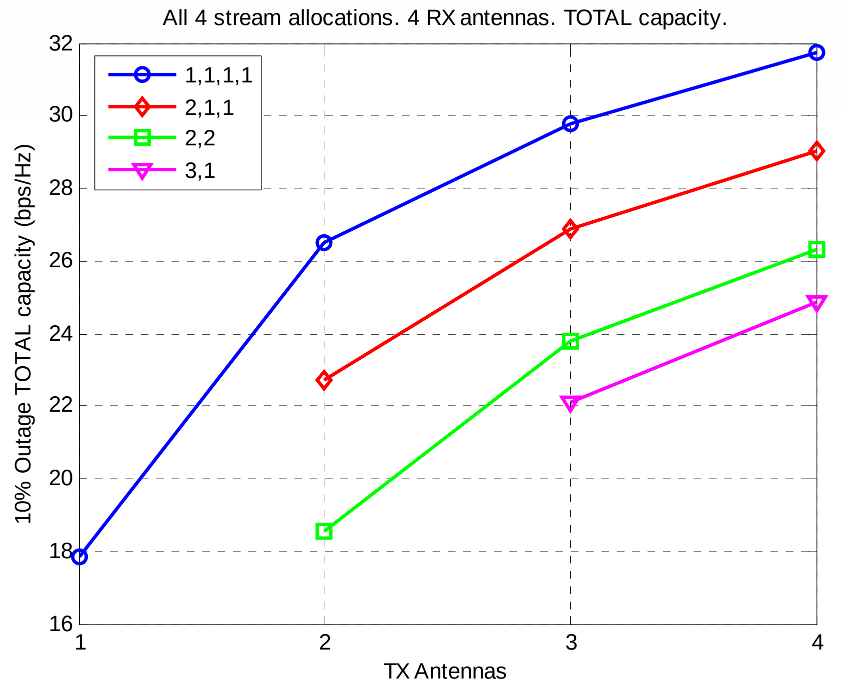
- Prefer to operate with a ‘few’ interferers if we must have >1
- With 2 users, can waterfill away from all interference by using only 2 streams each
- Abrupt change from 2 streams/user with 3 users to 1 stream/user with 4 users – again allows waterfilling away from interference

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

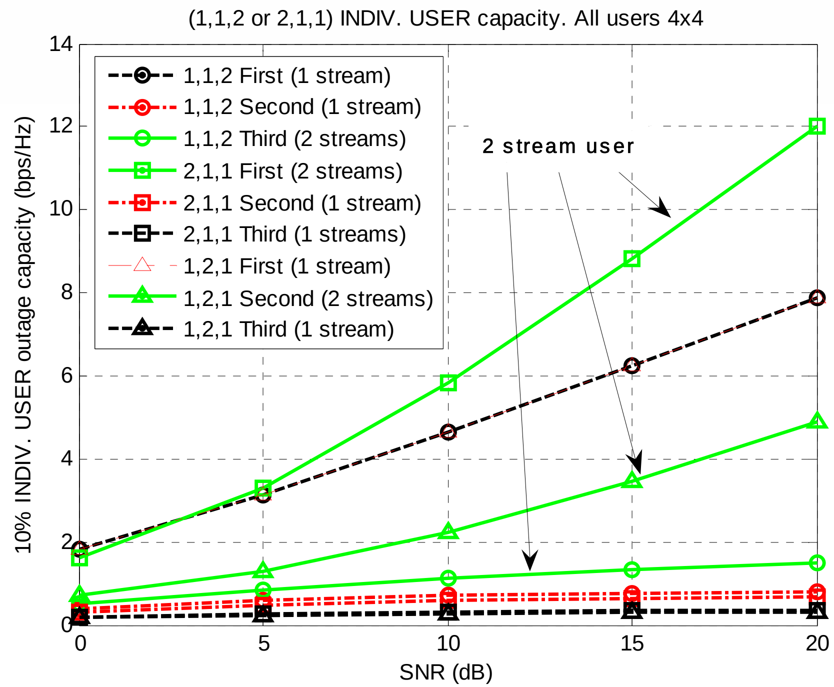
Block diagonalization – stream allocation



- 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

University of BRISTOL



- 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

University of BRISTOL

- 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

Acknowledgements

University of BRISTOL

EPSRC

Engineering and Physical Sciences Research Council

PHILIPS