UL/DL Mode Selection and Transceiver Design for Dynamic TDD Systems

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2016 Tyrrhenian International Workshop on Digital Communications, Livorno, Italy
14 Sept, 2016

- A. Tölli, J. Kaleva, G. Venkatraman & D. Gesbert, "Joint UL/DL Mode Selection and Transceiver Design for Dynamic TDD Systems", in Proc. 2016 IEEE Global Conference on Signal and Information Processing (GLOBALSIP), Washington, D.C., USA, Dec. 7–9, 2016

Dynamic TDD

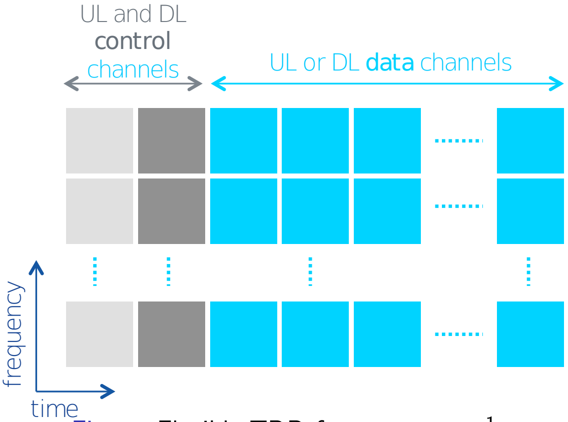


Figure: Flexible TDD frame structure[1]

- Significant load variation between adjacent cells
- Flexible UL/DL allocation provides large potential gains in spectral efficiency[2]
- More challenging interference management

[1] Nokia Networks, "5G radio access system design aspects", Nokia white paper, Aug. 2015. Available: http://networks.nokia.com/file/37611/5g-radio-access

[2] 3GPP TSG RAN WG1, "Study on scenarios and requirements for next generation access technologies TR 38.913," 3rd Generation Partnership Project 3GPP, www.3gpp.org, 2016

Dynamic TDD

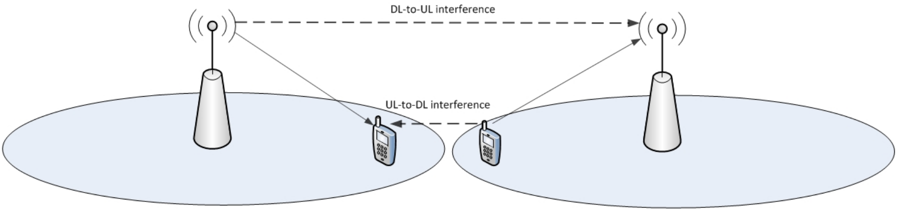
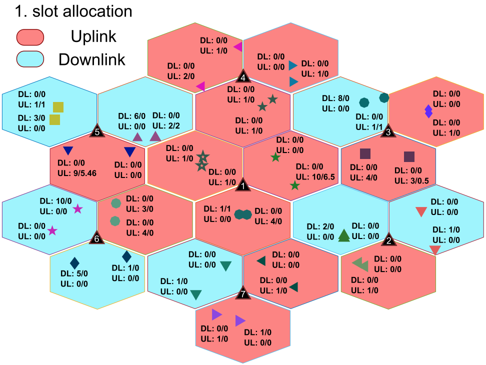


Figure: UL-DL/DL-UL interference in Dynamic TDD

- Additional UL-to-DL and DL-to-UL interference associated with the dynamic TDD
- Interference mitigated by coordinated beamforming.
- More measurements and info exchange also at the terminal side
- Similar interference scenarios in underlay D2D transmission[3]

[3] A. Tölli, J. Kaleva & P. Komulainen, "Mode Selection and Transceiver Design for Rate Maximization in Underlay D2D MIMO Systems", in Proc. IEEE ICC 2015, London, UK, June, 2015

System Model & Problem Formulation



- OFDM system with N sub-channels and N_B BSs, N_T TX antennas per BS
- K users each with N_R antennas

Goal: minimize the number of packets in BS/user queues via joint uplink (UL) / downlink (DL) cell mode selection, TX/RX design and resource allocation over spatial and frequency resources

Queueing Model

- Each user is associated with backlogged packets of size Q_k.
- Queued DL (UL) packets Q_k ($\bar{Q}_k$) of each user follows dynamic equation at the ith instant as

$$Q_k(i+1) = \Big[Q_k(i) - t_k(i)\Big]^+ + \lambda_k(i) \tag{1}$$

where $t_k = \sum_{n=1}^{N} \sum_{l=1}^{L} t_{l,k,n}$ denotes the total number of transmitted packets corresponding to user k

- λ_k represents the fresh arrivals of user k at BS b_k
- Separate user specific queues for UL and DL traffic

Objective

- Minimize the total number of backlogged packets in DL and UL[4]

$$\underset{t_k,\bar{t}_k}{\text{minimize}} \quad \sum_{k\in\mathcal{U}} \alpha_k|v_k|^q + \beta_k|u_k|^q \tag{2}$$

where α_k, β_k are arbitrary priority weights and

$$v_k = Q_k - t_k = Q_k - \sum_{n=1}^{N}\sum_{l=1}^{L} \log_2(1+\gamma_{l,k,n}) \tag{3}$$

$$u_k = \bar{Q}_k - \bar{t}_k = \bar{Q}_k - \sum_{n=1}^{N}\sum_{l=1}^{L} \log_2(1+\bar{\gamma}_{l,k,n}) \tag{4}$$

- $q = 1, 2, \ldots, \infty$ plays different role based on the value it assumes
  - Inherent maximum rate constraint: $\sum_{n=1}^{N} \sum_{l=1}^{L} t_{l,k,n} \leq Q_k$
- Special cases (when $Q_k > \sum_{n=1}^{N} \sum_{l=1}^{L} t_{l,k,n} \; \forall \; k$):
  - $q = 1$: Sum rate maximization
  - $q = 2$: Queue-Weighted Sum Rate Maximization (Q-WSRM)

[4] G. Venkatraman, A. Tölli, L-N. Tran & M. Juntti, "Traffic Aware Resource Allocation Schemes for Multi-Cell MIMO-OFDM Systems", IEEE Transactions on Signal Processing, vol. 64, no. 11, pp. 2730–2745, June 2016.

Spatial Overloading in SINR

DL SINR[5]

$$\Gamma_{l,k,n} = \frac{\left|\mathbf{w}_{l,k,n}^{\mathrm{H}}\,\mathbf{H}_{b_k,k,n}\,\mathbf{m}_{l,k,n}\right|^2}{\grave{N}_0 + \underbrace{\sum_{i\in\mathcal{U}\setminus\{k\}}\sum_{j=1}^{L}|\mathbf{w}_{l,k,n}^{\mathrm{H}}\mathbf{H}_{b_i,k,n}\mathbf{m}_{j,i,n}|^2}_{\text{DL-DL interference}} + \underbrace{\sum_{i\in\mathcal{U}\setminus\mathcal{U}_{b_k}}\sum_{j=1}^{L}|\mathbf{w}_{l,k,n}^{\mathrm{H}}\tilde{\mathbf{H}}_{i,k,n}\bar{\mathbf{m}}_{j,i,n}|^2}_{\text{UL-DL interference}}} \quad (5)$$

UL SINR

$$\bar{\Gamma}_{l,k,n} = \frac{\left|\bar{\mathbf{w}}_{l,k,n}^{\mathrm{H}}\,\mathbf{H}_{b_k,k,n}^{\mathrm{T}}\,\bar{\mathbf{m}}_{l,k,n}\right|^2}{\grave{N}_0 + \underbrace{\sum_{i\in\mathcal{U}\setminus\{k\}}\sum_{j=1}^{L}|\bar{\mathbf{w}}_{l,k,n}^{\mathrm{H}}\mathbf{H}_{b_k,i,n}^{\mathrm{T}}\bar{\mathbf{m}}_{j,i,n}|^2}_{\text{UL-UL interference}} + \underbrace{\sum_{i\in\mathcal{U}\setminus\mathcal{U}_{b_k}}\sum_{j=1}^{L}|\bar{\mathbf{w}}_{l,k,n}^{\mathrm{H}}\hat{\mathbf{H}}_{b_i,b_k,n}\mathbf{m}_{j,i,n}|^2}_{\text{DL-UL interference}}} \quad (6)$$

[5] Note that UL-DL and DL-UL interference terms in (5), and (6), respectively, include potential interference from all other-cell users. UL/DL mode selection per BS/user is handled separately via (relaxed) binary selection.

Queue Minimization with UL/DL Mode Selection

$$\text{min.} \quad \|\tilde{\mathbf{v}}\|_q + \|\tilde{\mathbf{u}}\|_q \tag{7a}$$

$$\text{s. t.} \quad \gamma_{l,k,n} \leq \Gamma_{l,k,n} \ \forall\ l,k,n \tag{7b}$$

$$\bar{\gamma}_{l,k,n} \leq \bar{\Gamma}_{l,k,n} \ \forall\ l,k,n \tag{7c}$$

$$\sum_{n=1}^{N} \sum_{k\in\mathcal{U}_b} \sum_{l=1}^{L} \|\mathbf{m}_{l,k,n}\|^2 \leq x_b P_{\max} \ \forall\ b \tag{7d}$$

$$\sum_{n=1}^{N} \sum_{l=1}^{L} \|\bar{\mathbf{m}}_{l,k,n}\|^2 \leq \bar{x}_{b_k} P_{\max}^{\text{UE}} \ \forall\ k \tag{7e}$$

$$x_b + \bar{x}_b = 1 \ \forall\ b, \quad x_b \in \{0,1\}, \quad \bar{x}_b \in \{0,1\} \tag{7f}$$

where $\tilde{v}_k \triangleq a_k^{\frac{1}{q}} \left(Q_k - \sum_{n=1}^{N} \sum_{l=1}^{L} t_{l,k,n}\right)$ and $t_{l,k,n} = \log(1+\gamma_{l,k,n})$

- Nonconvex (difference of convex) SINR constraints, and integer UL/DL selection constraints

Approximation of the SINR Constraints

- The DL SINR constraints in (7b) are relaxed as[6] (UL similarly)

$$\gamma_{l,k,n} \leq \frac{\left|\mathbf{w}_{l,k,n}^{\mathrm{H}} \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n}\right|^2}{\beta_{l,k,n}} = \frac{p_{l,k,n}^2 + q_{l,k,n}^2}{\beta_{l,k,n}} \quad (8)$$

$$\beta_{l,k,n} \geq \grave{N}_0 + \sum_{i\in\mathcal{U}\setminus\{k\}} \sum_{j=1}^{L} |\mathbf{w}_{l,k,n}^{\mathrm{H}} \mathbf{H}_{b_i,k,n} \mathbf{m}_{j,i,n}|^2 + \sum_{i\in\mathcal{U}\setminus\mathcal{U}_{b_k}} \sum_{j=1}^{L} |\mathbf{w}_{l,k,n}^{\mathrm{H}} \tilde{\mathbf{H}}_{i,k,n} \bar{\mathbf{m}}_{j,i,n}|^2 \quad (9)$$

where

$$p_{l,k,n} \triangleq \Re(\mathbf{w}_{l,k,n}^{\mathrm{H}} \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n}), \qquad q_{l,k,n} \triangleq \Im(\mathbf{w}_{l,k,n}^{\mathrm{H}} \mathbf{H}_{b_k,k,n} \mathbf{m}_{l,k,n})$$

- Difference of convex constraint solved via successive convex (linear) approximation (SCA)

[6] G. Venkatraman, A. Tölli, L-N. Tran & M. Juntti, "Traffic Aware Resource Allocation Schemes for Multi-Cell MIMO-OFDM Systems", IEEE Transactions on Signal Processing, vol. 64, no. 11, pp. 2730–2745, June 2016.

Binary Relaxation

- Binary variables $x_b, \bar{x}_b \in \{0,1\}$ are replaced by continuous variables $x_b, \bar{x}_b \in [0,1]$, $\forall b$
- Problem (7) becomes convex (for fixed receivers, at any given linearization point of the SINR constraints)
- Sparsity must be enforced! $\rightarrow$ Use a regularization function[7]

$$\text{minimize} \quad \|\tilde{\mathbf{v}}\|_q + \|\tilde{\mathbf{u}}\|_q + \underbrace{\psi \sum_{t=1}^{N_B} \left(\log(x_b + \epsilon) + \log(\bar{x}_b + \epsilon)\right)}_{\text{Concave}} . \quad (10)$$

successively linearized as

$$\text{minimize} \quad \|\tilde{\mathbf{v}}\|_q + \|\tilde{\mathbf{u}}\|_q + \psi \sum_{b=1}^{N_B} \left(\frac{x_b - x_b^{(i)}}{x_b^{(i)} + \epsilon} + \frac{\bar{x}_b - \bar{x}_b^{(i)}}{\bar{x}_b^{(i)} + \epsilon} \right) \quad (11)$$

[7] E. J. Candes, M. B Wakin, and S. Boyd, "Enhancing Sparsity by Reweighted l_1 Minimization," Journal of Fourier analysis and applications, vol. 14, no. 5-6, pp. 877–905, 2008.

Simulation Setup

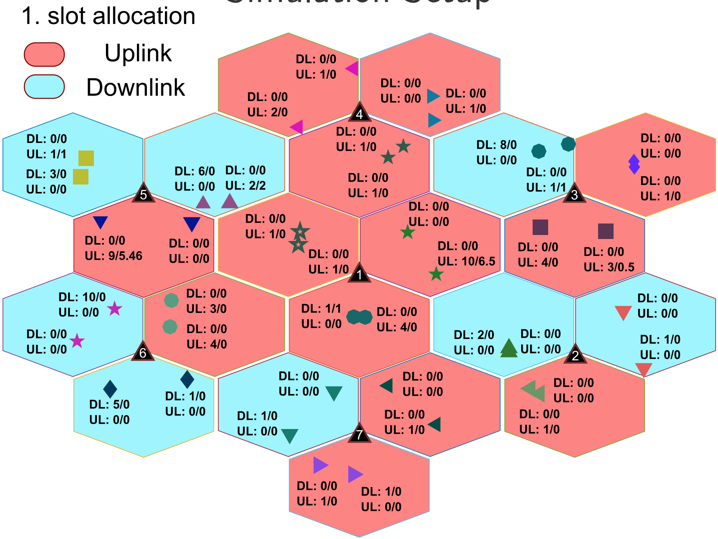


Figure: Final UL/DL allocation for a random drop of users and traffic states

Numerical Example

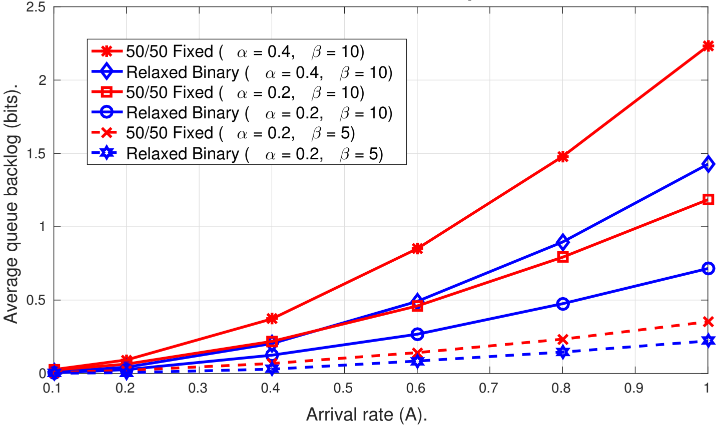


Figure: Average number of queued bits per user with varying packet arrival rates.

The mean arrival rate across all low and high rate demand users is $(1-\alpha)A + \alpha\beta A$.

Next Steps

- Decentralization, decoupling the problem
- Inter-carrier, inter-sector UL-DL interference
- Signalling, CSI acquisition
- Time-scale of changing UL/DL allocation?
- Impact of more practical traffic models