A Binary Power Control Scheme for D2D Communications

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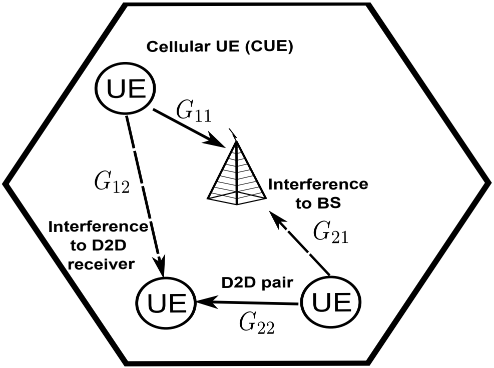
Why Binary Power Control for D2D ?



- Proposed BPC for D2D is practical and near-optimal
- Handles multiple D2D pairs and multi-cell systems
- Balances spectral and power efficiency

Outline

Outline

D2D Radio Resource Management

Binary Power Control (BPC)

- ON-OFF power control scheme*
  - Maximizes sum rate in single cell
  - Suboptimal in multi-cell systems

- Utility maximization is more appropriate for D2D
  - D2D layer $\rightarrow$ interference to cellular layer
  - Power saving is important

*A. Gjendemsjo, D. Gesbert, G. E. Oien and S. G. Kiani, "Optimal Power Allocation and Scheduling for Two-Cell Capacity Maximization," 2006 4th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, 2006, pp. 1-6.

Contributions

Existing Algorithms

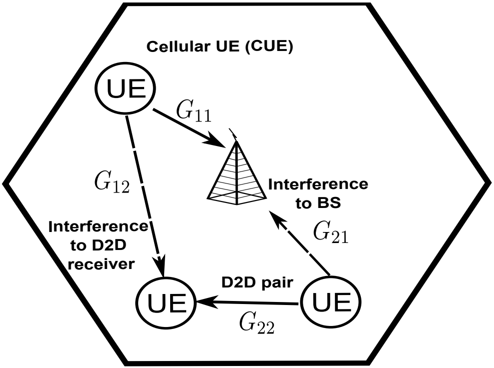
- Can maximize sum rate or minimize sum power
- High number of iterations
- BPC: No iterations, but does not handle power efficiency

Contributions

- Can we design utility optimal BPC schemes?
  - Yes! $\rightarrow$ sum rate maximization $+$ power minimization
- Is it optimal?
  - Single cell: optimal under mild assumptions
  - Multi-cell: heuristic near-optimal algorithm

Outline

Definitions (1)



- Single-cell cellular system
- I transmitters (including cellular and D2D)
- Effective path gain G_{ii} or G_{ij}
- Transmit power $\rightarrow P_i$; Noise power $\rightarrow P_N$

Definitions (2)

- SINR at the BS and at D2D receiver:

$$\gamma_1(\mathbf{p}) = \frac{P_1 G_{11}}{P_N + P_2 G_{21}}, \quad \gamma_2(\mathbf{p}) = \frac{P_2 G_{22}}{P_N + P_1 G_{12}}.$$

- Maximum achievable rate
$\rightarrow R_i(\mathbf{p}) = W \log_2 \Big(1 + \gamma_i(\mathbf{p})\Big), \quad i = 1, 2$
- Weight to trade sum rate maximization and power minimization $\rightarrow \omega$
- Achieved transmission rate of user $i \rightarrow s_i$

Problem Formulation

- Utility maximization problem

$$\underset{\mathbf{p},\mathbf{s}}{\text{maximize}} \sum_{i=1}^{2} \log(s_i) - \omega \sum_{i=1}^{2} P_i$$
$$\text{subject to } s_i \leq R_i(\mathbf{p}), i = 1, 2,$$
$$\mathbf{s} \succeq 0, \mathbf{p} \in \Omega.$$

- Why $\log(\cdot)$?
  - High rate increments $\not\approx$ High returns in terms of objective
- Has been studied prior to D2D communications*
  - Too many iterations $\rightarrow$ impractical

*G. Fodor, D. D. Penda, M. Belleschi, M. Johansson and A. Abrardo, "A comparative study of power control approaches for device-to-device communications," IEEE International Conference on Communications (ICC), Budapest, 2013, pp. 6008-6013.

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Problem Reformulation

- When $s_i = W \log_2 \Big(1 + \gamma_i(\mathbf{p})\Big)$, the problem is reformulated as

$$\underset{\mathbf{p}}{\text{maximize}} \sum_{i=1}^{2} \log \left(W \log_2 \Big(1 + \gamma_i(\mathbf{p})\Big)\right) - \omega \sum_{i=1}^{2} P_i$$
$$\text{subject to } \mathbf{p} \in \Omega.$$

- The objective function is now

$$O(P_1, P_2) = \log \Big[W^2 \log_2 (1 + \gamma_1(\mathbf{p})) \log_2 (1 + \gamma_2(\mathbf{p})) \Big] - \omega(P_1 + P_2).$$

Optimal Power Allocation (1)

Lemma 1

The optimal transmit power vector has at least one component equal to P_{max} provided that $\exists \alpha \in \mathbb{R}, \alpha > 1$ is a scaling factor and

$$\omega < \frac{\log\left[\frac{\log_2(1+\gamma_1(\alpha\mathbf{p}))\log_2(1+\gamma_2(\alpha\mathbf{p}))}{\log_2(1+\gamma_1(\mathbf{p}))\log_2(1+\gamma_2(\mathbf{p}))}\right]}{(\alpha-1)\left(P_1+P_2\right)}$$

- Optimal power allocation is between the alternatives
  - **Critical points on the boundaries of Ω:** Either $P_2 = P_{\text{max}}$ or $P_1 = P_{\text{max}}$, with P_1 or P_2 equals to $\frac{\partial O(P_1, P_{\text{max}})}{\partial P_1} = 0$ or $\frac{\partial O(P_{\text{max}}, P_2)}{\partial P_2} = 0$
  - **Corner points of Ω:** $(P_{\text{max}}, 0)$, or $(0, P_{\text{max}})$, or $(P_{\text{max}}, P_{\text{max}})$

Optimal Power Allocation (2)

- Since $\log(\cdot)$ is monotonically increasing

$$J(P_1, P_2) = \log\left[(1+\gamma_1)(1+\gamma_2)\right] - \omega(P_1 + P_2)$$

Result - Solutions at corner point

If the following inequality on P_1 holds, the optimal power allocation $(P_1^\star, P_2^\star)$ lies in the set of corner points,

$$TP_1^2 + VP_1 + X \geq -(NP_1^4 + QP_1^3),$$

where N, Q, T, V and X depend on $G_{ii}, G_{ij}, P_{\mathsf{max}}, P_N$.

- Result applies to 2 users sharing a single resource
- For some ω and channel conditions $\rightarrow$ optimal solution does not lie in the corner points

Outline

BPC in general settings

- Does BPC work in multi-cell ?
- New definitions
  - $Q \rightarrow$ available resources
  - $I_q \rightarrow$ number of users on resource q
  - $\mathcal{S} \rightarrow$ set of users with minimum transmitting power
- Algorithm performed by BS
- How to use BPC in practice? $\rightarrow$ Time scale of large scale fading
- How to acquire CSI? $\rightarrow$ D2D users can use reference signals (such as DMRS)

Algorithm - BPC for multiple D2D pairs

- BPC for multiple D2D pairs

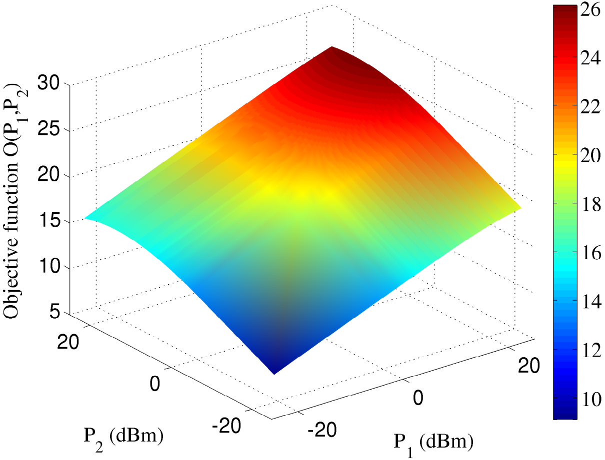
Input: $\mathbf{p}_0 = P_{\text{max}},\ O_0 = O(\mathbf{p}_0),\ l = 0,\ \mathcal{S} = \emptyset$
for $q = 1$ **to** Q **do**
  for $i = 1$ **to** I_q **do**
    $l = l + 1$
    $\mathbf{p}_l = \mathbf{p}_{l-1},\ O_l = O(\mathbf{p}_l)$
    $i^\star = \arg\max_{i \notin \mathcal{S}} O\Big((P_l)_i = 0, (\mathbf{p}_l)_{j \neq i}\Big)$
    if $(O_l)_{i^\star} > O_{l-1}$ **then**
      $(P_l)_{i^\star} = 0$
      $\mathcal{S} = \mathcal{S} + \{i^\star\}$
      $O_l = O(\mathbf{p}_l)$
    end if
  end for
end for
Output: $\mathbf{p}^\star = \mathbf{p}_l$

Outline

Simulation Parameters

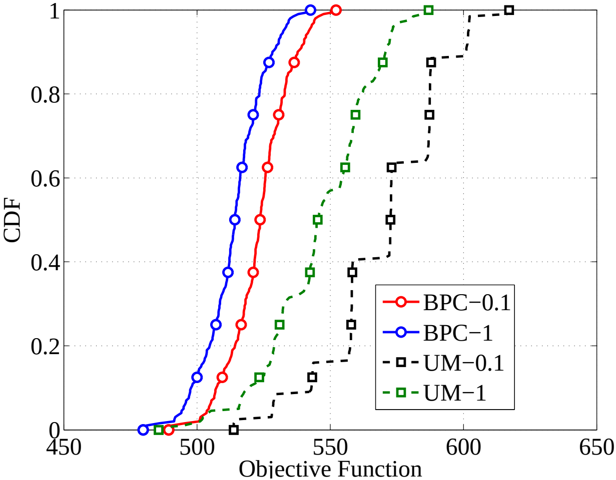
- Number of BSs $\rightarrow \quad 1/7$
- Number of cellular UEs per cell $\rightarrow \quad 1/2$
- Number of D2D pairs per cell $\rightarrow \quad 1/4$
- Number of RBs $\rightarrow \quad 1/6$
- Values of $\omega \rightarrow \quad 0.1/1$

Objective function with fixed ω and varying powers



- as power increases $\rightarrow$ utility increases $\rightarrow$ maximized at a corner point

Multi-cell case



- UM-ω outperforms BPC, but it is more complex $\rightarrow$ BPC is a good solution in practice

Outline

Take home message

- Under mild assumptions, BPC is optimal
- When suboptimal, BPC is close to optimal
- BPC is a practical D2D power control algorithm
  - BPC works without many iterations
  - BPC balances spectral and power efficiency
  - BPC handles multiple D2D pairs

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