QC^2 LinQ: QoS and Channel-Aware Distributed Link Scheduler for D2D Communication

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Problem and Contributions

Problem:

- Distributed link scheduling problem for Device-to-Device (D2D) Communication
  - Quality-of-service (QoS) (minimum average data rate) requirements
  - Time-varying channel conditions

Contributions:

- Two distributed resource allocation algorithms
  - QC LinQ:
    - QoS and channel aware priority assignment, SIR-threshold based yielding criterion
  - QC^2 LinQ:
    - Qos and channel aware priority assignment and yielding criterion
- Energy-level-based signaling procedure

System Model

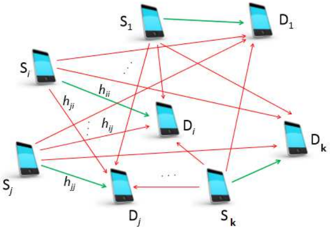


FIGURE – D2D communication model

Notation:

- $\mathcal{K} \in \{1, \ldots, \mathbf{K}\} \rightarrow$ Set of D2D links
- $\mathcal{U}^{\mathcal{T}} \in \{u_k^T, k \in \mathcal{K}\} \rightarrow$ Set of TXs
- $\mathcal{U}^{\mathcal{R}} \in \{u_k^R, k \in \mathcal{K}\} \rightarrow$ Set of RXs
- $\mathcal{S} \in \{1, 2, \ldots, \mathcal{S}\} \rightarrow$ Set of channel states
- $\pi_s \rightarrow$ Probability of system state s

Assumption:

- Channel state of each link
  $\Downarrow$
  Stationary stochastic process
- Each link operates at fixed power P

Scheduled Links and Achievable Date Rate

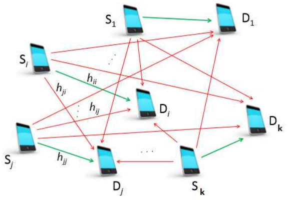


FIGURE – D2D communication model

Scheduling group and indicator:

Scheduling group: z$\subset \mathcal{K}$

$$q_z^s = \begin{cases} 1, & \text{if the link in scheduling group z are scheduled in a time slot with state s} \\ 0, & \text{otherwise} \end{cases}$$

Scheduling vector:

$$q_s = \left\{ \begin{array}{ll} q_z^s \in \{0,1\}, & \forall z \in \mathcal{Z} \\ \sum_{z\in\mathcal{Z}} q_z^s \leq 1 & \end{array} \right\} \forall s \in \mathcal{S}$$

Achievable data rate:

$$r_k^s(q_s) = \sum_{z\in\mathcal{Z}_k} q_z^s \log_2\Big(1 + \frac{h_{k,k}^s P}{\sum\limits_{k'\in z, k'\neq k} h_{k,k'}^s P + N_0}\Big)$$

Average data rate:

$$\sum_{s\in\mathcal{S}} \pi_s r_k^s(q_s)$$

Total average achievable sum rate:

$$\sum_{k\in\mathcal{K}} \sum_{s\in\mathcal{S}} \pi_s r_k^s(q_s)$$

Centralized Optimal Link Scheduling

Optimization Problem:

$$\begin{aligned} \max_{q} \quad & \sum_{k \in \mathcal{K}} \sum_{s \in \mathcal{S}} \pi_s r_k^s(q_s) \\ s.t. \quad & C_1: \quad \sum_{s \in \mathcal{S}} \pi_s r_k^s(q_s) \geq \zeta_k, \quad \forall k \in \mathcal{K} \\ & C_2: \quad q_s \in \mathcal{Q}_s, \forall s \in \mathcal{S} \end{aligned}$$

Solution:

Lagrangian Dual Problem:

$$\max_{q} \quad \sum_{k \in \mathcal{K}} \sum_{s \in \mathcal{S}} \pi_s r_k^s(q_s) + \sum_{k} \lambda_k [\sum_{s \in \mathcal{S}} \pi_s r_k^s(q_s) - \zeta_k]$$

$$\max_{q} \quad \sum_{k \in \mathcal{K}} \sum_{s \in \mathcal{S}} (1 + \lambda_k) \pi_s r_k^s$$

$$q_z^s = \begin{cases} 1, & \text{if z = arg max}_{z' \in \mathcal{Z}} \Psi_{z'}^s, \quad \forall z \in \mathcal{Z} \\ 0, & \text{otherwise} \end{cases}$$

$$\Psi_z^s = \sum_{k \in z} \sum_{s \in \mathcal{S}} (1 + \lambda_k) \pi_s \log_2(1 + \frac{h_{k,k}^s P}{\sum_{k' \in z, k' \neq k} h_{k',k}^s P + N_0}) \tag{1}$$

Update Lagrange Multiplier:

$$\lambda_k^{(t+1)} = \max\{0, \lambda_k^{(t)} - a^{(t)} v_k^{(t)}\}$$

where,

$$a^{(t)} = stepsize \qquad\qquad v_k^{(t)} = r_k^s - \zeta_k, \quad \forall k \in \mathcal{K}$$

Good News

- Global optimal solution

Bad News

- Computational complexity - 2^K
- Large signaling overhead

Developing Distributed Link Scheduling

Requirements:

- Small signaling overhead
- Low computational complexity
- Approximates optimal solution

Developing distributed algorithm:

- **Step 1**: Each link updates its weight parameter in each time slot as in (1) and (2).

$$\begin{aligned} \lambda_k^{(t+1)} &= \max\{0, \lambda_k^{(t)} - a^{(t)} v_k^{(t)}\} \\ v_k^{(t)} &= r_k^s - \zeta_k, \forall k \in \mathcal{K} \end{aligned} \tag{2}$$

- **Step 2**: The links in the scheduling group which has the largest sum of weighted achievable rates are scheduled as in (3)

$$\begin{aligned} q_z^s &= \begin{cases} 1, & \text{if } z = \arg\max_{z' \in \mathcal{Z}} \Psi_{z'}^s, \quad \forall z \in \mathcal{Z} \\ 0, & \text{otherwise} \end{cases} \\ \Psi_z^s &= \sum_{k \in \mathcal{Z}} (1 + \lambda_k) \log_2 (1 + \frac{h_{k,k}^s P}{\sum_{k' \in z, k' \neq k} h_{k',k}^s P + N_0}) \end{aligned} \tag{3}$$

Priority Assignment and Yielding Criterion

QoS and channel aware priority assignment:

Weighted achievable data rates:

$$\rho_k^{(t)} = (1 + \lambda_k) \log_2 (1 + \frac{h^s_{k,k} P}{\sum_{k' \in z, k' \neq k} h^s_{k',k} P + N_0}), \quad \forall k \in \mathcal{K} \tag{4}$$

Approximated weighted achievable data rates:

$$\rho_k^{(t)} = (1 + \lambda_k) \log_2 (1 + \frac{h^s_{k,k} P}{I + N_0}), \quad \forall k \in \mathcal{K} \tag{5}$$

- All links share their approximated weighted achievable data rate with each other
- Maintain a priority list $\rightarrow$ descending order of the approximated weighted achievable rates
- decide which link to schedule based on the priority list and yielding criterion

QCLinQ

- QCLinQ uses Qos and channel aware priority assignment and SIR based threshold technique

Signaling procedure:

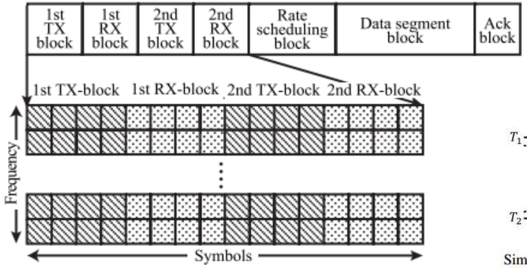


FIGURE – Structure of a time slot in QCLinQ

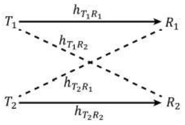
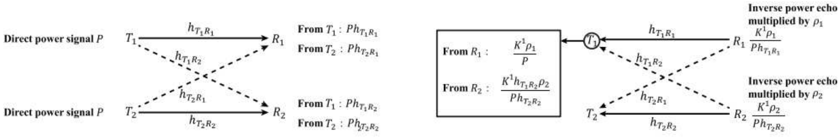


FIGURE – Simple example with two links

First TX-RX block:



(a) The first TX-block with two links. (b) The first RX-block with two links.

First TX-block and RX-block with two links.

At RXs

- Channel gain of its **own** link
- Weighted achievable rates

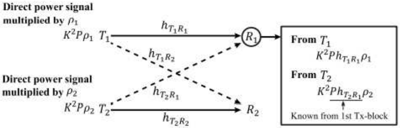
At TXs

- Its **own** weighted achievable data rate

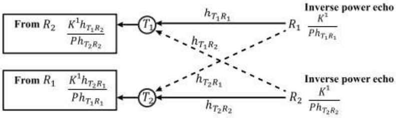
- What about weighted achievable rate of other links ?

Signaling procedure Contd.,

Second TX-RX block:



(a) The second TX-block with two links.



(b) The second RX-block with two links.

At RXs

- Weighted achievable rate of **all** links
- Schedule priorities of all links

T_i is allowed to transmit only if

$$\frac{Ph_{T_i,R_i}}{\sum_{j\in\mathcal{L}_i} Ph_{T_j,R_i}} > \gamma_{RX}$$

At TXs

- Weighted achievable rate of **all** links
- Schedule priorities of all links

T_i is allowed to transmit only if

$$\frac{Ph_{T_j,R_i}}{Ph_{T_i,R_j}} > \gamma_{TX}, \forall j \in \mathcal{L}_i'$$

QC^2 LinQ

QC^{2}LinQ uses Qos and channel aware priority assignment and yielding criterion

QoS and channel aware yielding criterion:

1. The decrement of the sum of the weighted achievable data rates of the higher priority links due to its transmission
2. Its own weighted achievable data rate

Approximated weighted achievable rate with the additional interference

$$\rho_j^{(t)} = (1+\lambda_j)\log_2\left(1+\frac{h_{j,j}^s P}{I + h_{k,j}^s P + N_0}\right), \quad \forall k \in \mathcal{K} \tag{6}$$

The decrement of the weighted achievable rate is

$$\rho_j^{(t)} = (1+\lambda_j)\log_2\left(1+\frac{h_{j,j}^s P}{I+N_0}\right) - (1+\lambda_j)\log_2\left(1+\frac{h_{j,j}^s P}{I + h_{k,j}^s P + N_0}\right)$$

$$\rho_j^{(t)} = (1+\lambda_j)\log_2\left(1+\frac{h_{k,j}^s P}{I+N_0}\right)$$

TX yielding criterion:

$$(1+\lambda_k)\log_2\left(1+\frac{h_{k,k}^s P}{I+N_0}\right) \geq \sum_{j\in\mathcal{L}_k}(1+\lambda_j)\log_2\left(1+\frac{h_{k,j}^s P}{I+N_0}\right) \tag{7}$$

QC^2 LinQ Signaling Procedure

Signaling procedure:

1st TX block	1st RX block	2nd TX block	2nd RX block	***3rd RX block***	Rate scheduling block	Data segment block	Ack block

FIGURE – Structure of time slot in QC^{2}LinQ

COMPARISON OF SIGNALING IN PROPOSED ALGORITHMS

	1st TX-block	**1st RX-block**	**2nd TX-block**	**2nd RX-block**	**3rd RX-block**
Transmission power in QCLinQ	P	$\frac{K^1\rho_i}{Ph_{T_iR_i}}$	$K^2P\rho_i$	$\frac{K^1}{Ph_{T_iR_i}}$	-
Transmission power in QC^{2}LinQ	P	K^2Pw_i	$K^2P\rho_i$	P	$K^2P\rho_i$
Information sharing in QCLinQ	-	-	RXs obtain ρ_i's	TXs obtain ρ_i's	-
Information sharing in QC^{2}LinQ	-	-	RXs obtain ρ_i's	TXs obtain w_i's	TXs obtain ρ_i's

Overhead comparison:

- Centralized scheduler - O(K^2)
- QCLinQ scheduler - O(4K)
- QC^{2}LinQ scheduler - O(5K)

Thank You :)