Algorithms for Optimal Fixed-Rate Routing and Power Allocation for Multi-Hop D2D Communication

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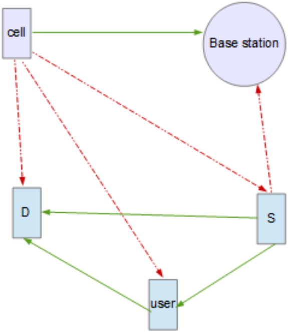
Problem Statement

There could be a multi hop route which gives better throughput than the direct link

Achieve maximum throughput between D2D source and destination, while causing minimum interference to the cellular network.

Choose optimal route and best link activation policy.

Uplink case



S: D2D source
D: D2D destination
M D2D users
N Base stations

- Every D2D link has a fixed target rate
- Only one D2D link is active in each time slot
- Fixed D2D source and destination.
- CSIT at D2D Tx.
- Locations of the D2D users known, locations of cellular users unknown
- Simplified path loss model, $P_r = \frac{P_t}{d^\alpha}$

For the uplink case, we have interference from

1. cellular users to D2D Rx
2. D2D Tx to the base station

Link feasibility analysis I

Link in outage if the interference from the D2D users to the base station is greater than a threshold, γ_{bs}.

MxM link feasibility matrix obtained using the steps given below.

Steps

- Interference plus noise power $P_{int}^{d_R}$
- Minimum transmit power for target SINR threshold, γ.

$$P_{d_T}^{d_R} = P_{int}^{d_R} + \gamma + 10\alpha \log(D_{d_T}^{d_R}) - 20 \log(|h_{d_T}^{d_R}|)$$

- Maximum transmit power for maximum interference at BS_i, γ_{bs}.

$$P_{d_T,BS_i}^{max} = \gamma_{bs} + 10\alpha log(D_{d_T,BS_i}) - 20 log(|h_{d_T}^{BS_i}|)$$

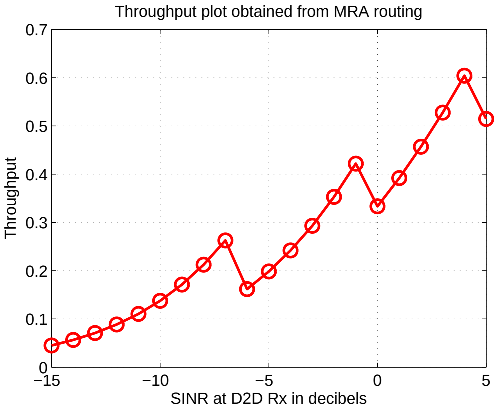
$$P_{d_T}^{max} = \min_{1 \leq i \leq N} P_{d_T,BS_i}^{max}$$

- Link $d_T \longrightarrow d_R$ infeasible if $P_{d_T}^{d_R} > P_{d_T}^{max}$

Max rates algorithm (MRA) for routing in fixed rate scheme

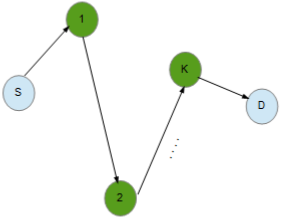
Use link feasibility matrix and Shannon's capacity formula to find rate matrix, R.

1. Initialize the rate matrix R_{MxM}. $r_{i,j}$ is the maximum rate on the link $i \longrightarrow j$, $r_{i,i} = 0 \forall i; k = 1$
2. $r_{min}(k) = \min_{i,j; r_{i,j} > 0} r_{i,j}$
3. throughput(k) = $\dfrac{r_{min}(k)}{dijkstra(T, S, D)}$
4. if throughput(k) = 0 ; Go to step 7.
5. $\forall i, j$ such that $r_{i,j} \leq r_{min}(k)$, set $r_{i,j} = 0$.
6. if $R \neq 0, k = k + 1$; Go to step 2.
7. $r_{opt} = r_{min}(arg\ max_k\ throughput(k))$



Throughput obtained from MRA routing algorithm for average fading channel

Link feasibility analysis II



Source to destination transmission via K relay nodes

Channel gains: $G = [g_{S1}(t), g_{12}(t), \ldots, g_{K-1,K}(t), g_{KD}(t)]$
Buffer lengths:
$B = [l_1, l_2, \ldots, l_{K-1}, l_K]$
Link states:
$L = [L_{S1}, L_{12}, \ldots, L_{K-1,K}, L_{KD}]$
where, $i \in \{S, 1, \ldots, K\}$ and
$j \in \{1, 2, \ldots, D\}$

Maximum interference at the nearest base station, BS_n is below γ_{bs} with minimum probability p_b.

$$Pr\{P_{i,BS_n} - 10\alpha \log(D_{i,BS_n}) + 10 \log(g_{ij}(t)) \leq \gamma_{bs}\} \geq p_b$$

$$P_{max,i} = 10 \log \left(- \frac{10^{0.1\gamma_{bs}} (D_{i,BS_n})^{\alpha}}{2\sigma_{ij}^2 ln(1 - p_b)} \right)$$

- Interference and noise power at D2D Rx, $P_{int,j}$
- Minimum D2D Tx power, $P_{ij}(t) = P_{int,j} + \gamma + 10\alpha \log(D_{ij}) - 10 \log(g_{ij}(t))$
- Link L_{ij} feasible iff $P_{ij}(t) \leq P_{max,i}$

Sequential link activation (SELA) scheme

- Empty data buffers to start with, all links are feasible.
- In the first time slot, select the first link.
  1. If the link is in outage, wait for the next time slot.
  2. Transmit otherwise
- Repeat the above step until all the packets are sent.

Outage probability

Outage probability of the link $i \longrightarrow j$:

$$p_{out,ij} = Pr\{P_{ij}(t) > P_{max,i}\}$$

$$p_{out,ij} = 1 - exp\left(- \frac{10^{0.1(\gamma + P_{int,j} - P_{max,i})} D_{ij}^{\alpha}}{2\sigma_{ij}^2} \right)$$

Delay on the link $i \longrightarrow j$:

$$w_{ij}^{SE} = \frac{1}{(1 - p_{out,ij})}$$

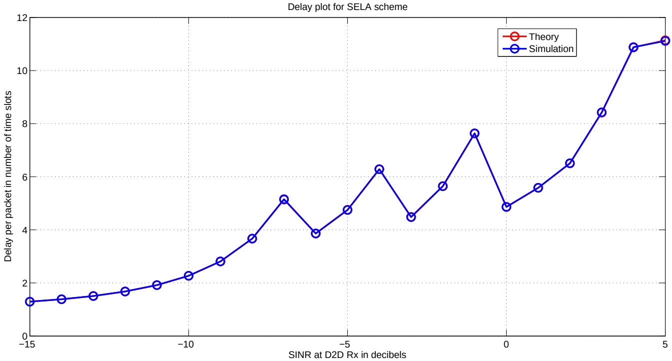
Total delay in the scheme:

$$W^{SE} = \sum_{i,j} \frac{1}{1 - p_{out,ij}}$$

Average packet delay from Little's law:

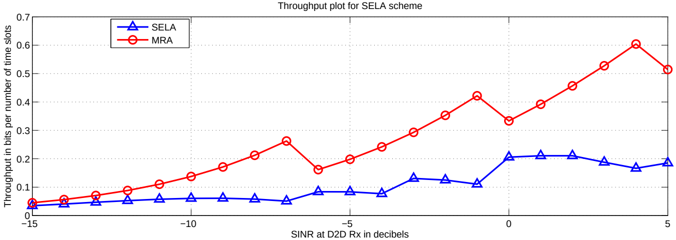
$$w_i = \frac{E[q_i]}{t_i}$$

Simulation results



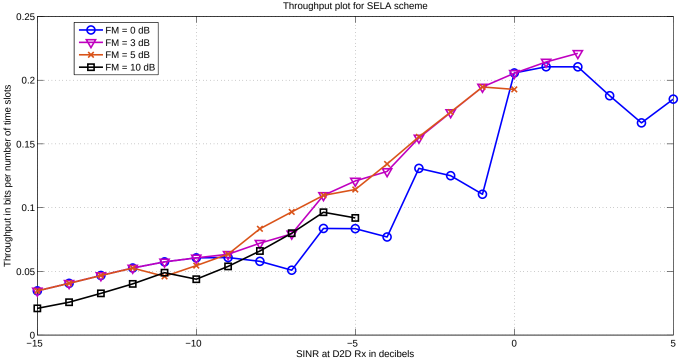
Average packet delay using the SELA scheme

Simulation results



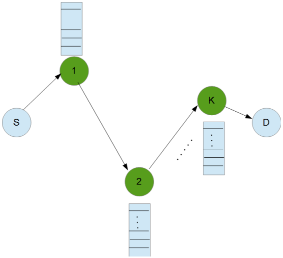
Comparison of throughput obtained from MRA and SELA

Simulation results



Throughput from SELA scheme for different fade margins

Opportunistic link activation



Source to destination transmission via K relay nodes

Maximum buffer length: L_{max}

Average queue length should be half the maximum size.

- $l_k = 0, \forall\ k = 1, 2, \ldots, K$.
- $L = [1, 1, \ldots, 1, 1]$.
- At every time slot, update L on based on link outage/success.
  1. If $l_k = L_{max}$, set $L_{k-1,k} = 0$ in L.
  2. If $l_k = 0$, set $L_{k,k+1} = 0$ in L.
- Maintain the buffer length at a threshold,
  $$l_{th} = \frac{L_{max}}{2} \forall\ k.$$
  1. $l_{min} = min\{l_k\}$
  2. $l_{max} = max\{l_k\}$
  3. Update L such that all the data buffers are half full.
- Choose one from all those links with $L_{ij} = 1$ in a uniform random manner.

Future Work

- Prove that a multi-hop D2D route gives better throughput than a single hop route when fade margin is considered.
- Design an algorithm to achieve optimal route with throughput considered for link activation as the metric.
- Find best route with opportunistic link activation in place.