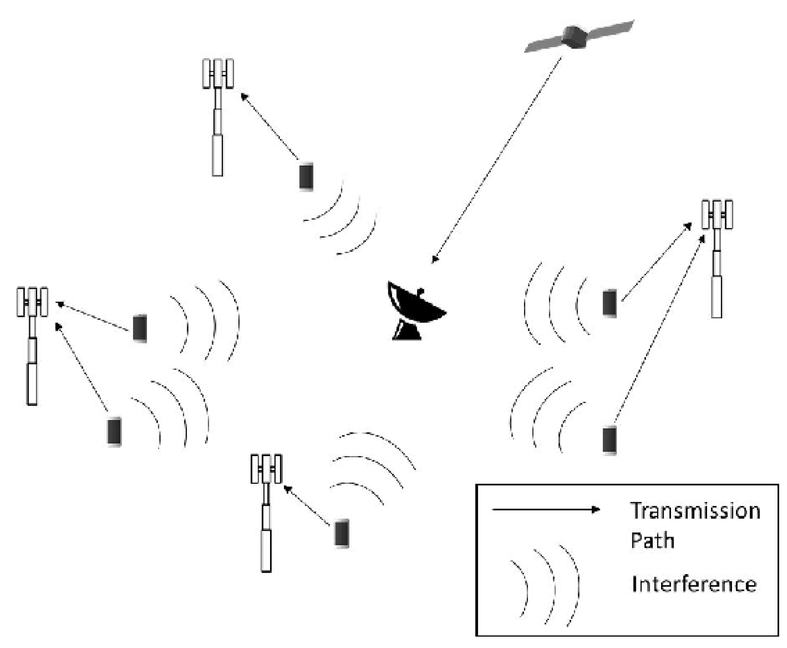
Ming Hsieh Department of Electrical Engineering

USC Viterbi School of Engineering

Efficient Resource Scheduling for an LTE Network in Shared Spectrum

Matthew Clark and Konstantinos Psounis

Introduction



- Pending auction of 1695-1710 MHz
- New RF spectrum sharing
  - Meteorological satellite downlinks primary
  - Mobile wireless, e.g., LTE, uplinks secondary
- New resource scheduling algorithms needed
  - Power, frequency and time allocation
  - Interference protection constraints

Scheduling Optimization Problem

$$\begin{aligned}
\text{maximize} \quad & \textstyle\sum_{b=1}^{N_b} \sum_{i=1}^{N_u^b} U(A_i^b, T_i^b, P_i^b) && \leftarrow \text{Utility} \\
\text{subject to} \quad & A_i^b \in \{1, \dots, M\}, \forall i, b \\
& T_i^b \in \{0, \dots, M+1-A_i^b\}, \forall i, b \\
& A_i^b + T_i^b \le A_m^b, \forall i, m, b : A_m^b \ge A_i^b \\
& Pr\{\textstyle\sum_{j \in W_p} I_j \ge I_t\} \le p_t \\
& 0 \le P_i^b, \forall i, b, \\
& T_i^b P_i^b \le P_{max}, \forall i, b,
\end{aligned}$$

$$I_j = \sum_{b=1}^{N_b} \sum_{i=1}^{N_u^b} P_i^b g_{i,j}^{1,b} z_{i,j}^b x_{i,j}^b$$

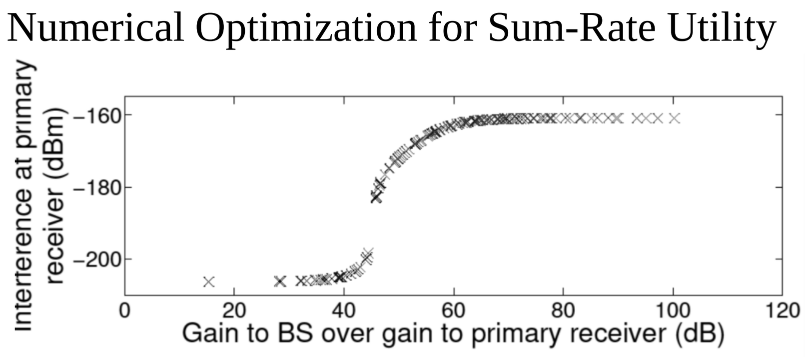
- Utility
- Non-overlapping and contiguous frequency allocations
- Interference protection
- Device transmit power limits

Equal Interference Power Allocation (EIPA)

Sub-problem

$$\begin{aligned}
\text{maximize} \quad & \textstyle\sum_{i=1}^{N_u} U(P_i) \\
\text{subject to} \quad & Pr\{I_j \ge I_t\} \le p_t \\
& I_j = \textstyle\sum_{i=1}^{N_u} P_i g_i^1 z_i \\
& 0 \le P_i \le P_{max}, \forall i,
\end{aligned}$$

Numerical Optimization for Sum-Rate Utility



Observations

- Power allocations causing equal interference at the victim receiver will allow more total transmit power across the secondary network
- Some subscriber devices may need to be restricted from operating in interference protected frequencies
- Utility for a single device should be positively correlated with channel gain to base station, and negatively correlated with channel gain to victim receiver

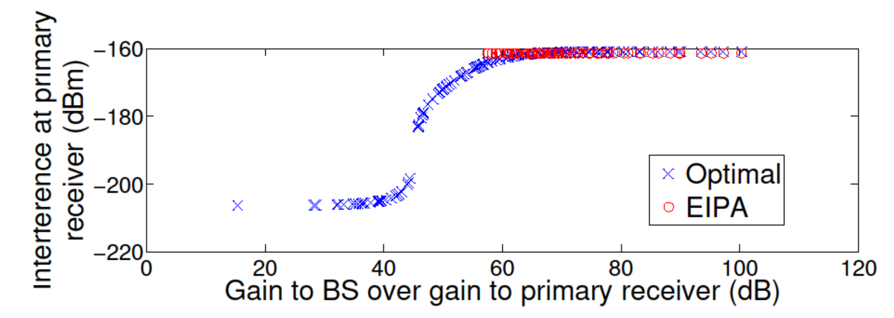
Algorithm:

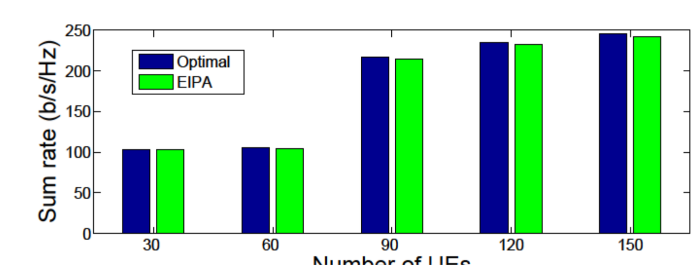
(Sum-Rate and F-W Approx.*)

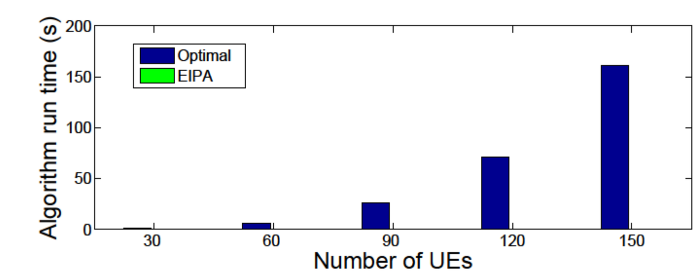
1: $L \leftarrow 1$, $s = (\sigma_{dB}(\ln 10)/10)^2$
2: $R_{best} \leftarrow 0$
3: Order UEs by descending gain ratio
4: $\mu \leftarrow I_{th} + \frac{5}{\ln 10}[\ln(\frac{L+e^s-1}{L^3}) - 2Q^{-1}(p_{th})\sqrt{\ln(\frac{L+e^s-1}{L})-s}]$
5: $P_{new}(1:L) \leftarrow 10^{\mu/10}/g_1(1:L)$
6: $P_{new}(L+1:N_u) \leftarrow 0$
7: $R_{new} \leftarrow \sum_{i=1}^{L} \log_2\left(1 + \frac{P_{new}(i)g_2(i)}{N_2}\right)$
8: **if** $R_{new} > R_{best}$ **then**
9: $\quad R_{best} \leftarrow R_{new}$
10: $\quad P_{best} \leftarrow P_{new}$
11: $\quad L \leftarrow L+1$
12: $\quad$ goto 4
13: **else**
14: $\quad$ **return** P_{best}

*L. Fenton, The sum of log-normal probability distributions in scatter transmission systems, IRE Trans. Comm. Syst., vol. 8, no. 1, March 1960

EIPA Performance



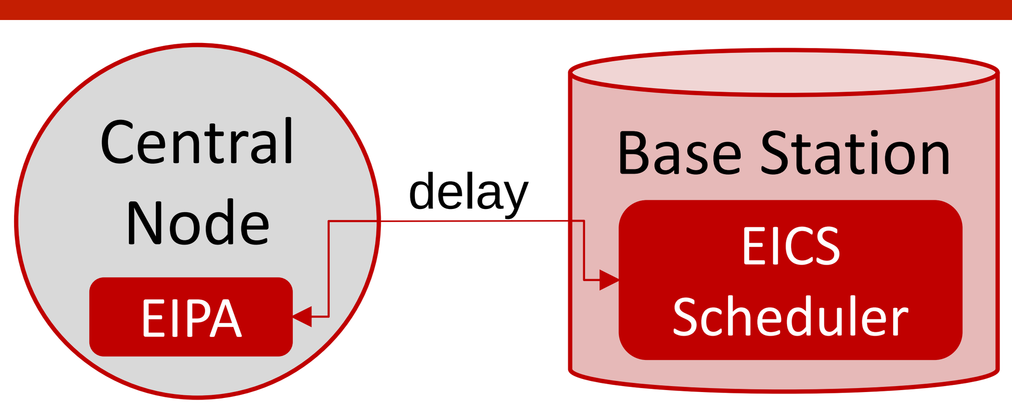




Equal Interference Contribution Scheduling (EICS)

1. Run EIPA on all subscriber devices in network
2. For subscribers allocated zero power by EIPA, set their utility functions to zero in the protected resource blocks
3. For subscribers allocated nonzero power by EIPA, set their utility functions to reflect this power limit
4. Perform resource block assignment with any frequency domain assignment algorithm using the modified utility functions
5. Repeat step 4 at each scheduling time slot. Repeat steps 1 through 3 at a suitable interval

Practical Considerations



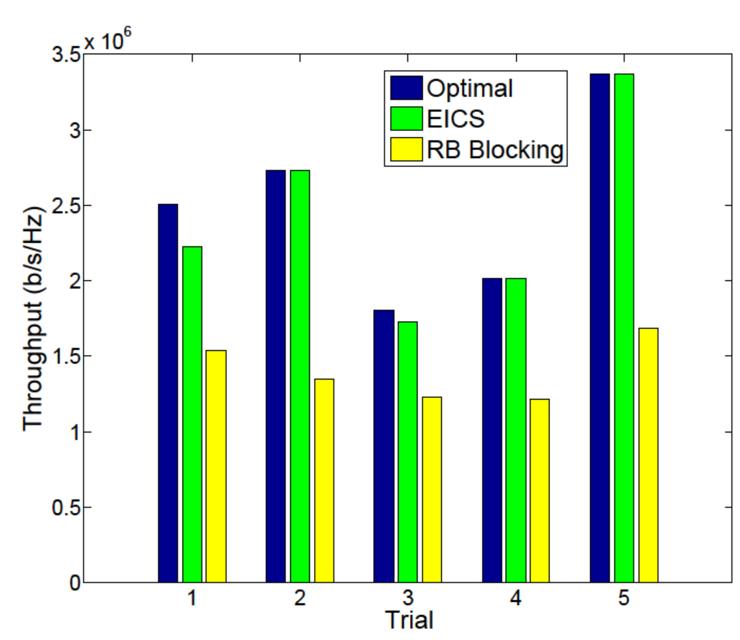
- Delay
- Traffic priorities
- Filtering
- Information requirements and uncertainty

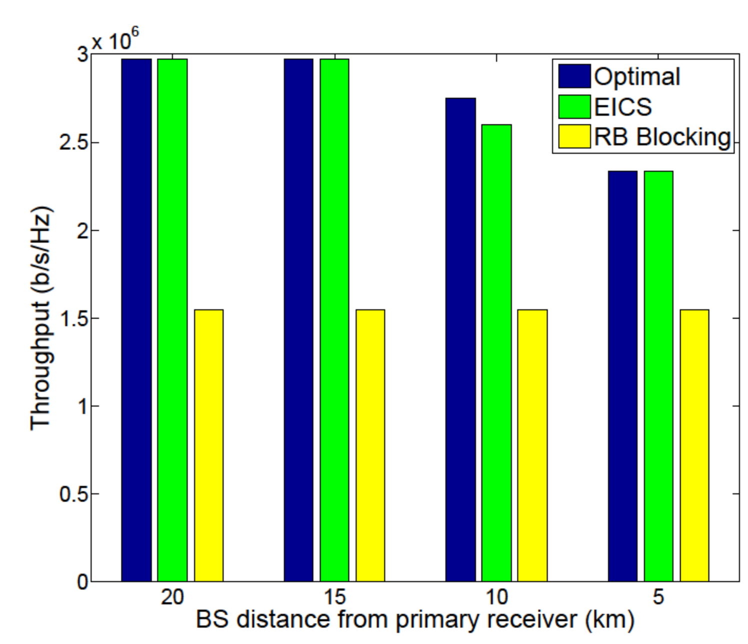
Parameter	Description
M	Number of schedulable resource blocks
N_b	Number of base stations in the network
N_u^b	Number of subscribers on base station b
N_u	Number of subscriber devices in the network
N_2	Thermal noise at base station receivers
σ_{dB}	Standard deviation of channel gain
I_t	Harmful interference threshold
p_t	Maximum probability that I_t may be exceeded
W_p	The set of resource blocks subject to interference protection
P_{max}	Maximum subscriber device transmit power
P_i^b	Subscriber transmit power per resource block
$g_{i,j}^{1,b}$	Mean channel gain of subscriber to primary/victim receiver
$g_{i,j}^{2,b}$	Mean channel gain of subscriber to intended base station
$z_{i,j}^b$	Random variable for channel gain uncertainty e.g., shadowing
A_i^b	Subscriber leftmost resource block assignment
T_i^b	Subscriber number of resource blocks assigned

EICS Simulation Results Achieved Network Throughput

Small-Scale Trials

Ten node network to facilitate comparison to optimal scheduling result found through global search

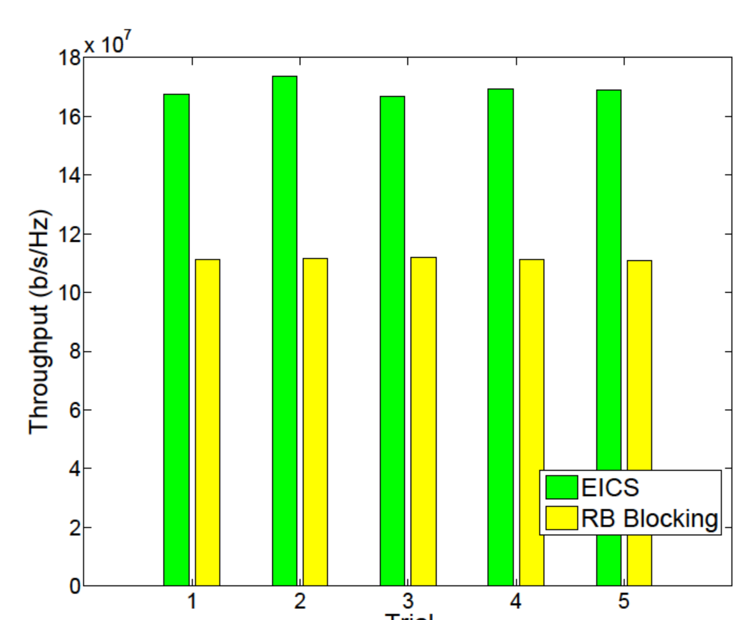


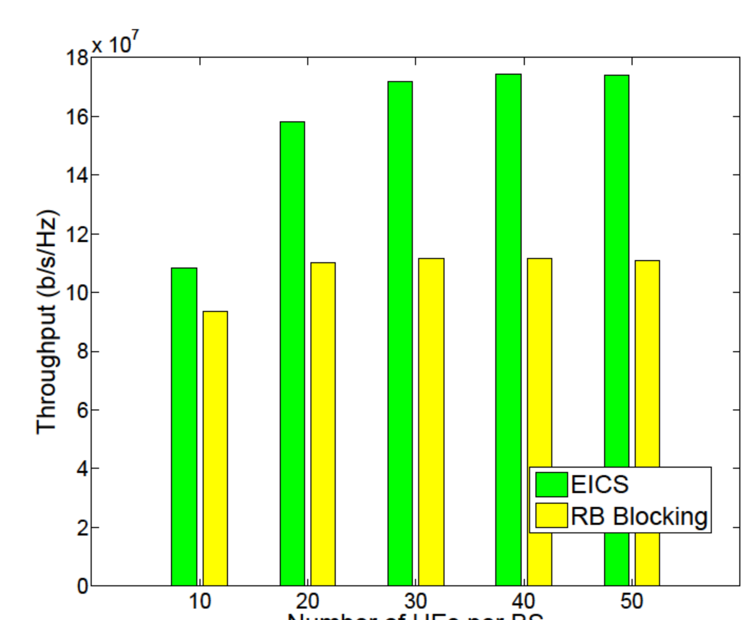


50% of resource blocks are interference protected in all trials shown

Large-Scale Trials

1000 node network comparison against simple approach of never using interference protected resource blocks





40% of resource blocks are interference protected in all trials shown

CLARKMA@USC.edu

Ming Hsieh Institute
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