Security Level:

Optimization in Radio Resource Management

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Introduction: who we are?

One of core business: serving operators

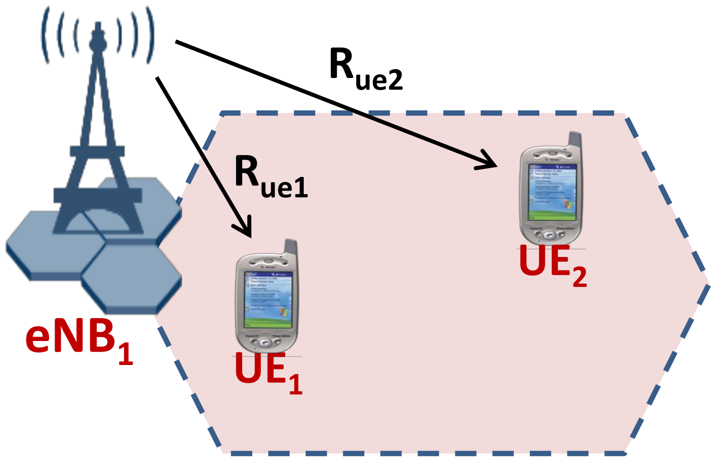
Huawei LTE Base station
with several antennas

Our Customers

Content

- Scheduler
- Power control
- Overview and Outlook

1. Scheduling in Downlink.



User (UE) n has data rate R_n and average rate X_n
(exponential moving average)

$$X_n(t+1) =$$
$$= X_n(t) + \beta \left(R_n(t) - X_n(t) \right)$$

Scheduler problem: which UE to serve each 1 ms?

1. "**Max Rate**".
   If we want to maximize total throughput $U = \sum_k R_k$
   we serve UE n with maximal rate: $R_n = \max_k R_k$.
   -- It doesn't consider fairness: UE with low R won't be served.
2. "**Round Robin**".
   To give equal amount of resources
   we serve each 1 ms different UE
   -- It doesn't consider changing rate *R(t)* and is not efficient.

Proportional Fair scheduler.

3. "**PF**".
   We serve UE *n* with maximal metric R_n / X_n .
   -- It cares about fairness by using X_n
   and significantly exploits fast fading effect by using R_n .

Consider Utility $U = \sum_n \log X_n$.

PF seems to be the gradient ascend for *U* as

$$\dot{U}(t) = \sum_n \frac{\dot{X}_n(t)}{X_n(t)} \approx \frac{R_k(t)}{X_k(t)} ,$$

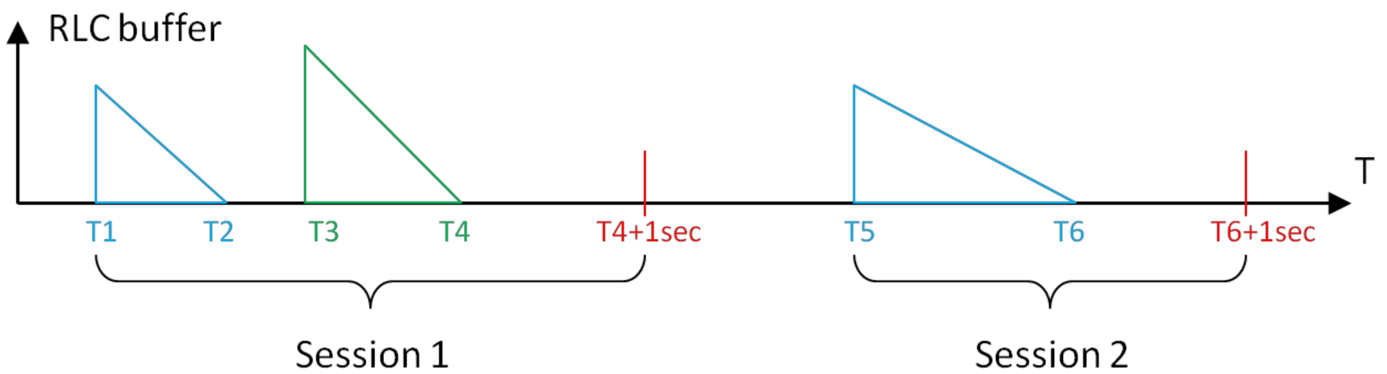
where $k = \text{argmax}_n R_n / X_n$.

Theorem (Kelly, Kushner-Whiting, Agrawal-Subramanian, Stolyar…).
In the case of Full buffer (all UE have infinitely large needs),
PF is asymptotically optimal wrt sum-log Utility as t →∞.

Packets and stochastic statement.

In many cases **Full buffer** is not adequate.

Bursty traffic (aka finite buffer model) models are required.



Stochastic statement:

UE *n* gets files of size A_n^p ,

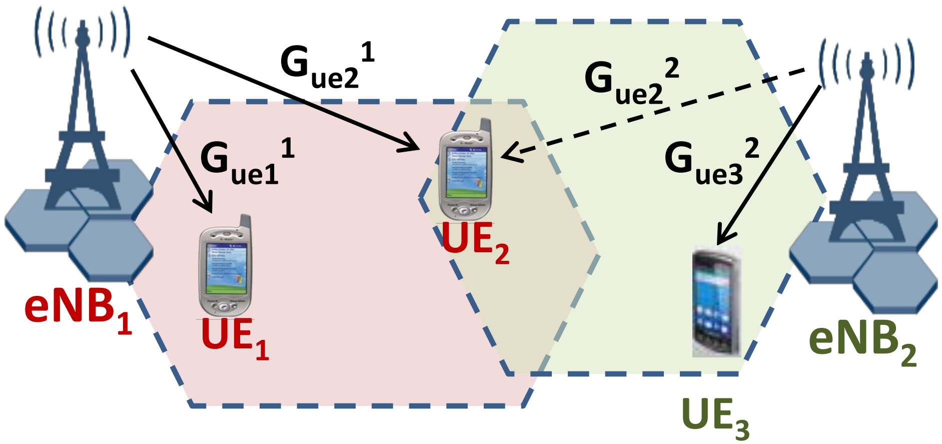
Time intervals between packets T_n^p are random variables.

Data rates $R_n(t)$ are random values.

Depends on scheduler serving times are dT_n^p.

Utility to be maximized is Download rate: $U = \sum_{n,p} \frac{A_n^p}{dT_n^p}$

2. Power control vs Interference.



Interference =
noise signal from neighbor cells

Data rate *R* can be estimated by Shannon law:

$$R_n^c = \mathrm{BW}^c \ln(1 + \mathrm{SINR}_n^c)$$

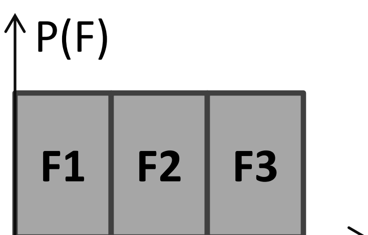
where BW^c – bandwidth of cell *c* (number of resource blocks),
SINR_n^c – signal to noise and interference ratio for UE *n* in cell *c*,

$$\mathrm{SINR}_n^c = \frac{\mathrm{Signal}_n^c}{\mathrm{noise} + \sum_{c_1 \neq c} \mathrm{Signal}_n^{c_1}} = \frac{G_n^c\, P^c}{\mathrm{noise} + \sum_{c_1 \neq c} G_n^{c_1}\, P^{c_1}}$$

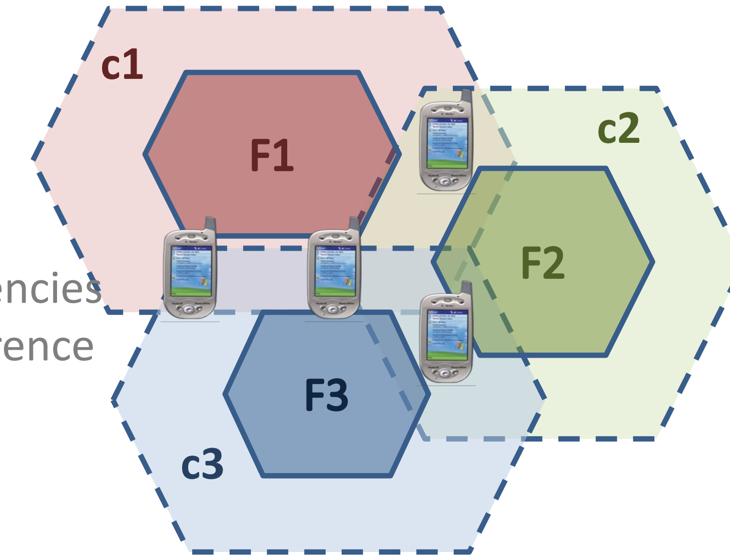
G_n^c – channel (*c-to-n*) gain, P^c – cell *c* power.

Interference cancelation idea: frequency reuse

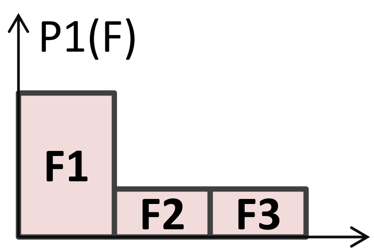
Unnecessary high power for cell center UE
and large interference for cell edge UE



Different frequencies
and low interference
for cell edge UE



Sufficient power for cell center UE



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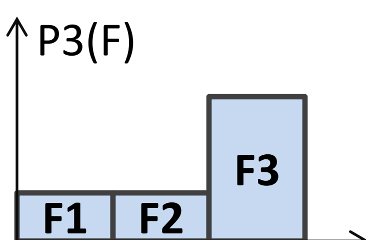

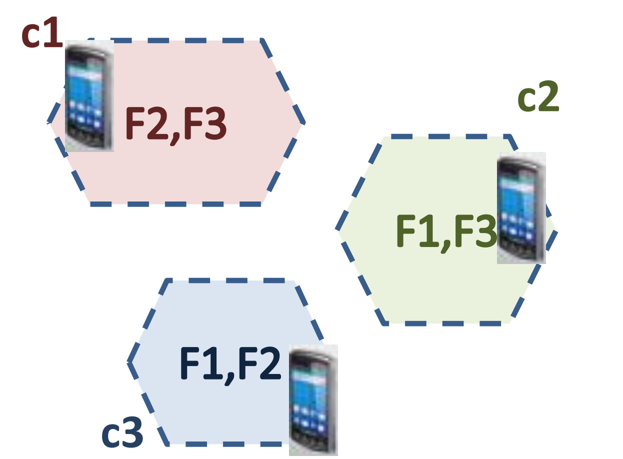

Power control statement.

Power control maximizes the network Utility

$$U(X) = \sum_{c=1}^{C} U^c = \sum_{c=1}^{C} \sum_{n=1}^{N_c} \log X_n^c$$

with respect to cell powers $P^c \leq P^{max}$

on the period of hundreds (thousands) of scheduler times.

Applying Shannon law $R = \log(1 + \mathrm{SINR})$ to $U(X)$ we have

$$U(P) = \sum_{c=1}^{C} \sum_{n=1}^{N_c} \log\left(\mu_n^c \, \mathrm{BW}^c \log\left(1 + \frac{G_n^c P^c}{N + \sum_{c_1 \neq c} G_n^{c_1} P^{c_1}}\right)\right)$$

where μ_n^c are the fractions of resources that UE n gets in cell c: $\sum_{n=1} \mu_n^c < 1.$

μ_n^c depends on Scheduler and generally speaking on Power control.

Decentralized solution (Stolyar).

SINR$_n^c$

Cell Utility: $U^c = \sum_{n=1}^{N_c} \log X_n^c = \sum_{n=1}^{N_c} \log(\mu_n^c R_n^c), \quad R_n^c = \log\left(1 + \frac{G_n^c P^c}{N + \sum_{c_1 \neq c} G_n^{c_1} P^{c_1}}\right)$

Derivation of U^c wrt self power: $\frac{\partial U^c}{\partial P^c} = \sum_{n=1}^{N_c} \frac{1}{X_n^c} \mu_n^c \frac{\partial R_n^c}{\partial P^c} = \sum_{n=1}^{N_c} \frac{1}{X_n^c} \mu_n^c \frac{G_n^c}{1 + \mathrm{SINR}_n^c} > 0$

Derivation of U^c wrt interf power: $\frac{\partial U^c}{\partial P^{c_1}} = \sum_{n=1}^{N_c} \frac{1}{X_n^c} \mu_n^c \frac{\partial R_n^c}{\partial P^{c_1}} = \sum_{n=1}^{N_c} \frac{1}{X_n^c} \mu_n^c \frac{-G_n^c P^c G_n^{c_1}}{1 + \mathrm{SINR}_n^c} \left(\frac{\mathrm{SINR}_n^c}{G_n^c P^c}\right)^2 < 0$

Derivation of U^{c1} wrt interf power: $\frac{\partial U^{c_1}}{\partial P^c} = \sum_{n=1}^{N_{c_1}} \frac{1}{X_n^{c_1}} \mu_n^{c_1} \frac{\partial R_n^{c_1}}{\partial P^c} = \sum_{n=1}^{N_{c_1}} \frac{1}{X_n^{c_1}} \mu_n^{c_1} \frac{-G_n^{c_1} P^{c_1} G_n^c}{1 + \mathrm{SINR}_n^{c_1}} \left(\frac{\mathrm{SINR}_n^{c_1}}{G_n^{c_1} P^{c_1}}\right)^2 < 0$

Coordination: information transfer between cells.
On cell c following values are known: X_n^c, G_n^c, G_n^{c1}, SINR$_n^c$; and $\mu_n^c = f(P)$ is estimated,
so both dU^c / dP^c and dU^c / dP^{c1} can be calculated.

It's a separate complicated problem

Greedy gradient algorithm.
If all neighbor cells c_1 transfer to cell c their dU^{c1} / dP^c
then cell c can calculate network utility derivation dU / dP^c
and increase/decrease its power P^c correspondingly to its sign.

Overview

- Mathematics and theorems do bring money
- And don't forget about fairness

Outlook

- Many ~~complicated~~ interesting problems are waiting for you