Lec21-mwf

Thursday, February 15, 2018 2:52 PM

K-Tier HetNet - 15min

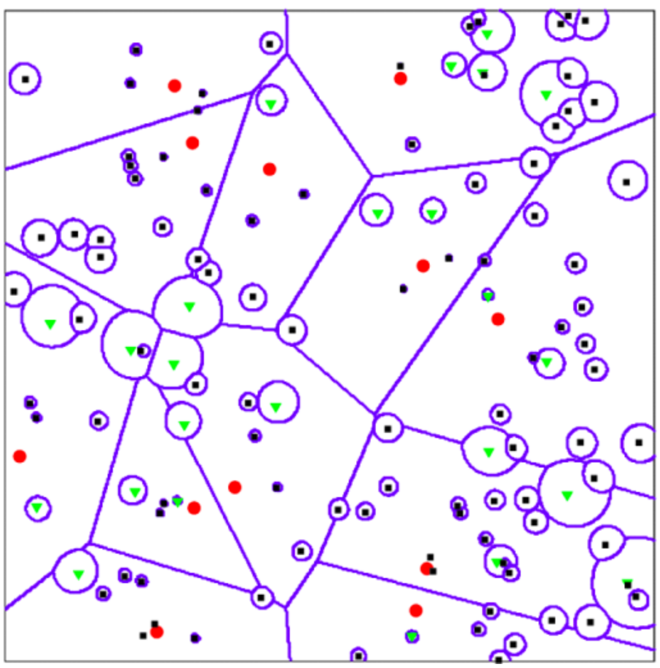
Tuesday, February 13, 2018 3:18 PM

- Now let us look at heterogeneous networks
- There are k tiers (macro-, micro-, pico-, femto-)
- Focus again on the downlink, and consider a mobile at the origin
- The BSs at tier i is distributed according to PPP with intensity λ_i
  - Each of them uses power P_i
  - λ_i, P_i vary across tiers

Determine the serving BS

- Since the transmission powers are different, the serving BS is usually not the closest BS
- May decide based on power & distance

$$P_i \cdot r^{-n}$$



Modeling and Analysis of K-Tier Downlink Heterogeneous Cellular Networks
Harpreet S. Dhillon, Radha Krishna Ganti, Franc¸ois Baccelli and Jeffrey G. Andrews,

- This complicates the calculation of both the received signal and the location of the interferers.
- The above reference consider an alternate model.
  Let $\beta \geq 1$ be the SINR threshold.
  When $\beta \geq 1$, there can be at most one BS with $SINR \geq \beta$.
  Then, the mobile is served by the BS ~~with~~ the largest SINR.
- Note that Raleigh fading is part of the SINR calculation. (May be unrealistic when multi-path fading changes quickly.)

Coverage Probability

$$P\{\text{coverage}\}$$

SINR from BS x_i

$$= P\left\{ \bigcup_{\substack{i=1,\cdots K, \\ x_i \in \Phi_i}} \{ SINR(x_i) \geq \beta_i \} \right\}$$

True if $\beta_i > 1$

$$= \sum_{i=1}^{K} \sum_{x_i \in \Phi_i} P\left\{ SINR(x_i) \geq \beta_i \right\}$$

$$= \sum_{i=1}^{K} E\left[\sum_{x_i \in \Phi_i} \mathbb{1}\{ SINR(x_i) \geq \beta_i \} \right]$$

$$= \sum_{i=1}^{K} \lambda_i \iint_{R^2} dx_i^2 \cdot P\left[\frac{P_i h_{x_i} \|x_i\|^{-n}}{I_{x_i} + \sigma^2} \geq \beta_i \right]$$

$$= \sum_{i=1}^{K} \lambda_i \iint_{R^2} dx_i^2 \underbrace{P\left[h_{x_i} \geq \frac{\beta_i (I_{x_i} + \sigma^2)}{P_i \|x_i\|^{-n}} \right]}$$

$$\overset{\text{''}}{=} E\left[P\left\{ h_{x_i} \geq \frac{\beta_i (I_{x_i} + \sigma^2)}{P_i \|x_i\|^{-n}} \right| I_{x_i} \right]$$

$$= E\left[e^{-\mu \cdot \frac{\beta_i (I_{x_i} + \sigma^2)}{\|x_i\|^{-n}}} \right]$$

$$= e^{-\frac{\mu \beta_i \sigma^2}{P_i \|x_i\|^{-n}}} \cdot \underbrace{\mathcal{L}_{I_{x_i}}\left(\frac{\mu \beta_i}{P_i \|x_i\|^{-n}} \right)}$$

can be calculated as before since I_{x_i} is the total interference of all BSs.

- In particular, for any x_i, the rest of the BSs still follow a PPP with the same rate

$$\mathcal{L}_{I_{x_i}}(s) = E\left[e^{-s \sum_{j=1}^{K} \sum_{x_j \in \Phi_j} P_j\, g(x_j) \|x_j\|^{-n}} \right]$$

$$= E\left[\prod_{j=1}^{K} \prod_{x_j \in \Phi_j} \frac{\mu}{\mu + s P_j \|x_j\|^{-n}} \right]$$

$$= \prod_{j=1}^{K} E\left[\prod_{x_j \in \Phi_j} \frac{\mu}{\mu + s P_j \|x_j\|^{-n}} \right]$$

$$= \prod_{j=1}^{K} \exp\Big(-\lambda_j \underbrace{\iint_{R^2} \left(1 - \frac{\mu}{\mu + s P_j \|x_j\|^{-n}}\right) dx_j^2}_{\left(\frac{sP_j}{\mu}\right)^{\frac{2}{n}} \iint_{R^2} \left(1 - \frac{1}{1 + \frac{sP_j}{\mu}\|x_j\|^{-n}}\right) d\left(\frac{x_j}{\sqrt[n]{\frac{sP_j}{\mu}}}\right)^2} \Big)$$

$$= \prod_{j=1}^{K} \exp\Big(-\lambda_j \left(\frac{sP_j}{\mu}\right)^{2/n} \underbrace{\iint_{R^2} \left(1 - \frac{1}{1 + \|x_j\|^{-n}}\right) dx_j}_{C(n)} \Big)$$

$$= \exp\left\{-\left(\frac{s}{\mu}\right)^{2/n} \cdot C(n) \sum_{j=1}^{K} \lambda_j P_j^{2/n}\right\}$$

— since $s = \dfrac{\mu \beta_i}{P_i \|x_i\|^{-n}}$

$$\mathcal{L}_{I_{x_i}}\left(\frac{\mu \beta_i}{P_i \|x_i\|^{-n}}\right)$$

$$= \exp\left\{-\left(\frac{\beta_i}{P_i \|x_i\|^{-n}}\right)^{2/n} C(n) \sum_{j=1}^{K} \lambda_i P_j^{2/n}\right\}$$

— Go back to the probability of coverage

$P\{\text{coverage}\}$

$$= \sum_{i=1}^{K} \lambda_i \iint_{R^2} dx_i^2 \; e^{-\frac{\mu \beta_i \sigma^2}{P_i \|x_i\|^{-n}}} \cdot$$

$$\exp\left\{-\left(\frac{\beta_i}{P_i \|x_i\|^{-n}}\right)^{2/n} C(n) \sum_{j=1}^{K} \lambda_i P_j^{2/n}\right\}.$$

$\sigma^2 = 0$

— If $\sigma^2 = 0$

$P\{\text{coverage}\}$

$$= \sum_{i=1}^{K} \lambda_i \iint_{R^2} dx_i^2 \exp\left\{-\left(\frac{\beta_i}{P_i}\right)^{2/n} \cdot \|x_i\|^2 \; C(n) \cdot \sum_{j=1}^{K} \lambda_j P_j^{2/n}\right\}$$

— Note that

$$\iint_{R^2} dx^2 \, e^{-s\|x\|^2}$$

$$= \int_0^{+\infty} 2\pi R \, dR \, e^{-sR^2}$$

$$= \pi \int_0^{+\infty} e^{-sR^2} \cdot dR^2$$

$$= \frac{\pi}{s}$$

S

- Hence

$P\{\text{coverage}\}$

$$= \sum_{i=1}^{K} \lambda_i \cdot \lambda \cdot \frac{1}{\left(\frac{\beta_i}{P_i}\right)^{2/n} C(n) \cdot \sum_{j=1}^{K} \lambda_j P_j^{2/n}}$$

$$= \frac{\lambda}{C(n)} \frac{\sum_{i=1}^{K} \lambda_i P_i^{2/n} \beta_i^{-2/n}}{\sum_{j=1}^{K} \lambda_j P_j^{2/n}}$$

Implication:

- If $\beta_i = \beta$, the coverage probability simplifies to

$$\frac{\lambda}{C(n)} \frac{1}{\beta^{2/n}}$$

- This is independent of the density and power of all tiers! Why?

Extensions

(1) Closed access: the mobile can only access a subset B of Tiers. When $\sigma^2 = 0$

$$P\{\text{coverage}\} = \frac{\lambda}{C(n)} \cdot \frac{\sum_{i \in B} \lambda_i P_i^{2/n} \beta_i^{-2/n}}{\sum_{j=1}^{K} \lambda_j P_j^{2/n}}$$

- closed access typically reduce coverage

(2) Load: when $\sigma^2 = 0$, the fraction N_j of mobiles served by tier j is (open access)

$$\overline{N_j} = \frac{P\{\bigcup_{X_j \in \phi_j} SINR(X_j) \geq \beta_j\}}{P\{\bigcup_{i=1}^{K} \bigcup_{X_i \in \phi_i} SINR(X_i) \geq \beta_i\}}$$

$$= \frac{\lambda_j P_j^{2/n} \beta_j^{-2/n}}{\sum_{i=1}^{K} \lambda_i P_i^{2/n} \beta_i^{-2/n}}$$

- Load per tier-j BS scales as $P_j^{2/n} \beta_j^{-2/n}$
- At the same β_j, smaller power tends to have smaller load.
- May decrease β_j to attract more mobiles to small cells

$\rightarrow$ cell biasing or range extension.

Scaling Laws - 5min

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Although we have discussed a few optimal algorithms, their complexity can often be high. for ad hoc wireless networks.

If we just want the network to perform reasonably well, perhaps we can use simpler algorithms.

What are the rule-of-thumb for such algorithms?

- Should we use long hops or short hops?
- How important is it to avoid hot-spots
- How far should the reuse distance be, i.e. how far should we seperate concurrent transmitting nodes?

Instead of bury the answers in some complex optimization problems, the study of scaling laws can sometimes offer surprisingly simple and intuitive answers

- only order optimal
- simple (back-of-envelop)
- give important guidelines.

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