SMALL CELL NETWORKS: SPEED BASED POWER ALLOCATION

by

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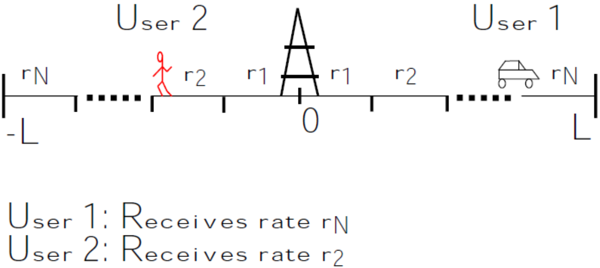
Outline

- Problem description
- Speed dependent performance measure
- Maximum velocity supported by system
- Optimal power: finite number of classes
- Continuous optimal power law
- Numerical results
- Conclusions and future directions

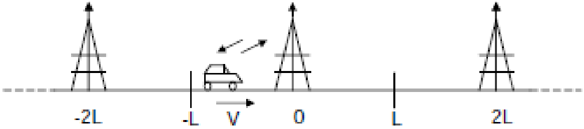
Problem description



- Short radius cell network.
- Good service to cell edge users.

Problem description contd..

- Mobility management.
- Increase in handover rate.
- Unacceptable rate of call drop.
- Optimal cell size increases with velocity.
- Increase power.



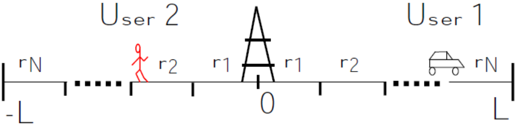
Power allocation

- Allocate power based on speed.
  - Finite number of velocity classes.
    - Allocate equal power to each class.
  - Continuous power allocation.
    - Allocate power based on exact speed.
- Discrete law converges to continuous one.

Assumptions

- No interference.
- Symmetry in both directions.
- User speed does not change during call.

Notations and Terminology



- $2N$ disjoint segments $\{A_n\}_{n \in \mathbb{N}}$.

$$\mathbb{A}_n := \left[\frac{(n-1)L}{N}, \frac{nL}{N}\right] \mathbf{1}_{\{n>0\}} + \left[\frac{nL}{N}, \frac{(n+1)L}{N}\right] \mathbf{1}_{\{n<0\}}$$

$$\mathbb{N} := \{-N, \cdots, -1, 1, \cdots, N\}$$

- Rate regions $\mathbb{R} := \{r_1, \ldots, r_N\}$
  - Decreasing set
- Path loss factor β

Notations and Terminology

- Poisson Arrivals
  - External arrivals
    - Arrival from external world (λ_e).
  - Handover arrivals
    - sub-stream of external arrivals whose service is not completed in the previous cell (λ_h).
- Velocity of user (V)
- Number of bytes to be transmitted $S \backsim expo(\mu)$
- Resources
  - K number of servers.
- Probabilistic arrival in each segment
  - Position of arrival with distribution $\Pi := \{\pi_n\}_n$
- Information to initiate the HO
  - extra bytes to be exchanged: $s_h \ll S$

Speed dependent performance measure

- Hand over probability
  - Probability of External call handing over ($P_{e,ho}$)
  - Probability of HO call again handing over ($P_{h,ho}$)
- Expected service time
- HO arrival rate ($\lambda_{h;L}$)
- Overall expected service time

$$\bar{b} = \left(\frac{\lambda_L}{\lambda_L + \lambda_{h,L}} b_e + \frac{\lambda_{h,L}}{\lambda_L + \lambda_{h,L}} b_h \right).$$

Speed dependent performance measure

- Load factor (ρ)

$$\rho = \frac{1}{K}(\lambda_L + \lambda_{h,L})\bar{b}.$$

- Busy probability (M/G/K/K queue)

$$P_{Busy} = \frac{\rho^K/K!}{\sum_{k=0}^{K}\rho^k/k!} \quad \text{(Erlang loss formulae)}$$

Claim

Optimizers of ρ and P_{busy} are same.

Maximum velocity supported by system

Useful communication is possible only if

$$g^N(L) > s_h \quad a.s.$$

Theorem

When $\beta > 1$, there exists a limit on the maximum velocity that can be supported by the system for a given power P

$$V_{lim}(P) := \frac{1}{s_h} r_0 \sum_{n=-N}^{N} |n|^{-\beta} P d_0^{1-\beta}. \quad \square$$

Optimal power: Finite number of classes

- Divide users in I disjoint intervals based on speed

Theorem

Assume $C_{h,ho} - \mu s_h C_{e,ho} > 0$ and assume that the following matrix is positive definite,

$$\mathcal{P}_V := \begin{bmatrix} p_1 + \frac{p_1^2}{p_I} & \frac{p_1 p_2}{p_I} & \cdots & \frac{p_1 p_{I-1}}{p_I} \\ \frac{p_1 p_2}{p_I} & p_2 + \frac{p_2^2}{p_I} & \cdots & \frac{p_2 p_{I-1}}{p_I} \\ & & \vdots & \\ \frac{p_1 p_{I-1}}{p_I} & \frac{p_{I-1} p_2}{p_I} & \cdots & p_{I-1} + \frac{p_{I-1}^2}{p_I} \end{bmatrix} > 0.$$

Then the power allocation that minimizes ρ while satisfying the average power constraint equals:

$$P_i^*(L; \bar{P}) = \bar{P} + \frac{\mu s_h L^{\beta-1}}{C_{h,ho}} \left(\frac{1}{\Upsilon_i} - \sum_j p_j \frac{1}{\Upsilon_j} \right). \tag{1}$$

Continuous optimal power law

- Accurate estimate of velocity.

Optimal power law that optimizes load factor ρ, and satisfies

$$\int_{V_{min}}^{V_{max}} P(v)p_V(v)d(v) \leq \bar{P}.$$

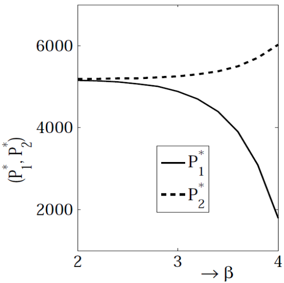
Theorem

The power function $P^*(.)$ that optimizes ρ, while satisfying the average power constraint equals:

$$P^*(v) = \bar{P} + \frac{1}{C_{h,ho}}\mu s_h L^{\beta-1}\left(v - E[V]\right). \quad \square \tag{2}$$

Numerical results

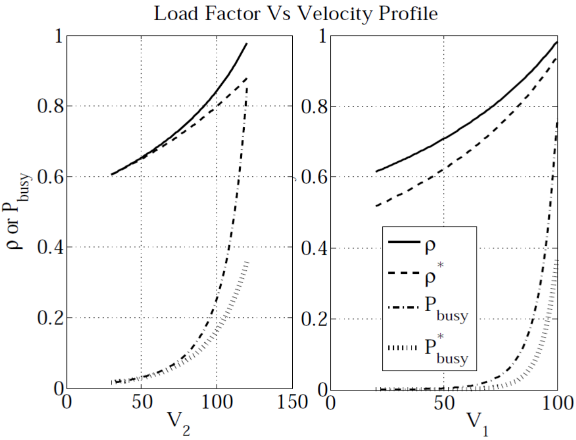
- More the losses (path-loss factor) are, more diverse the two allocated powers are.



Settings
$N = 3 \; d_0 = 5$
$r_0 = .4 d_0^{\beta} \; \gamma = 0.5$
$K = 500$
$\lambda = 10^{-7} \; s_h = 0.2$
$\mu = 0.000001$
$(\Upsilon_1, \Upsilon_2) =$
$(.067, .011)$
$(p_1, p_2) = (0.2, 0.8)$
$\bar{P} = 0.0001, L = 160$

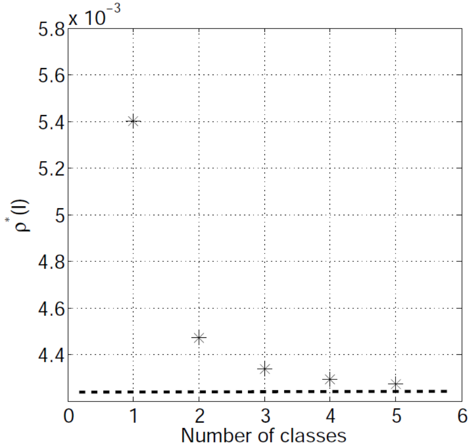
Power allocated optimally to two user classes

Numerical results contd...



Comparison of performance with and without optimal power allocation

Numerical results contd...



ρ^* decreases with number of classes and approaches to continuous law

Conclusions

- Model to incorporate speed based design variation in allocated power.
- Closed form expression for optimal power allocation.
  - optimal for busy/drop probability
  - Discrete power law
  - continuous power law (fine optimal power control)
- Linear variation in optimal power with user speed
- Large improvement in busy probability with optimal power law
- Best improvement with continuous power law.

Thank you!!!