The Tragedy of the Interdomain Routing Commons

Andra Lutu*♣, Marcelo Bagnulo♣
* Institute IMDEA Networks, Madrid
♣ University Carlos III of Madrid, Spain

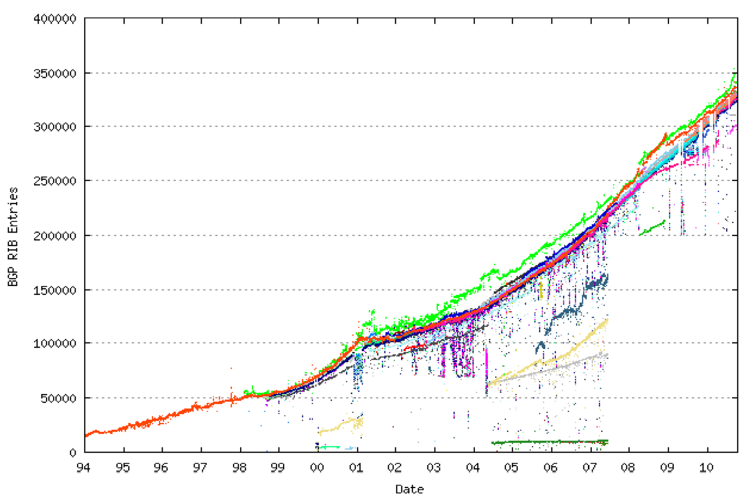
Introduction

➢ **Why Ases deaggregate?**
- Traffic engineering
- Increase security (prefix hijack)

But….

➢Deaggregated prefixes bloat the global routing table

➢***The Tragedy of the Commons*** [7]



➢Common resource = ***BGP routing table***

➢More specific prefixes => explosive inflation of the GRT [1,3]

➢ASes deaggregate on the expense of others

➢***Externalized*** costs
- This problem generates ***tragedy*** in the interdomain routing

➢Incentives for BGP route deaggregation can be analyzed using *game theory*

➢Routing table growth is a case of *the tragedy of the commons*

➢The tragedy of the Internet commons can be avoided using *payments*

The Game Theoretic Model

➢***Game theory*** approach on well-known problems of interdomain routing

- A ***game*** is…. the basic tool of game theory
  - ***Players***
  - ***Actions and preferences***
  - ***Outcomes***

➢*The Problem of the Internet Routing Commons*

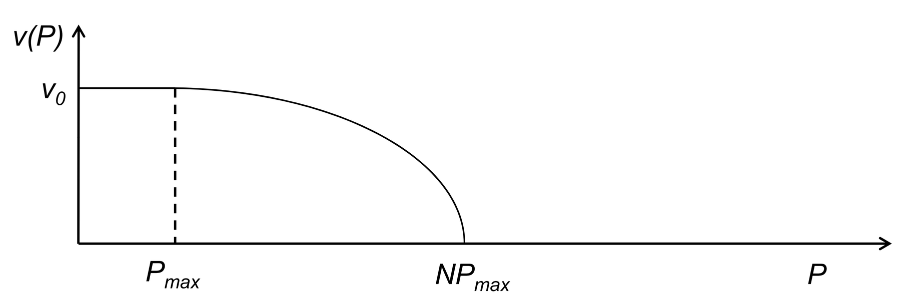
- ***Players***: *N* Ases
  - Model Ases as ***rational agents***
  - We assume that we can ***reduce each AS to one router***

- ***Strategy***: choosing the number of prefixes to announce in the Internet, p_i
  - Maximum number of prefixes that can be fitted into a routing table: P_{max}
  - Total number of prefixes in the routing table: P
  - We do not consider filtering

- ***Payoff function***:

$$u_i(p_i, p_{-i}) = \underbrace{p_i\, v(P)}_{\text{total benefit}} - \underbrace{c \min\{P, P_{max}\}}_{\text{total cost}}$$

- $v(P)$ = value each AS receives for each prefix
  - $V'(P) < 0$
  - $V''(P) < 0$
  - $V(P) = 0$, if $P > NP_{max}$



➢Analyze the game theoretic model

➢Prove that the interaction of the Ases generates tragedy

➢Avoiding *the tragedy of the commons*
- Private ownership
- Social rules/norms, external control
- Mechanism design

Game Analysis and Payment Mechanism

➢***Nash Equilibrium* analysis**

➢**Solve:** $\max_{p_i} \{u_i(p_i, p^*_{-i})\}$

- $(p^*_1, p^*_2 \ldots p^*_N)$ is the NE of the game
- if $P < P_{max}$ => $v_0 = c$
- if $P > P_{max}$ => $v(P) + p_i v'(P) = 0$

➢***Social Welfare* analysis**

➢**Solve:** $\max_P \left\{ \sum_i u_i(p_i, p^*_{-i}) \right\}$

- $(p^{**}_1, p^{**}_2 \ldots p^{**}_N)$ is the SW of the game
- if $P < P_{max}$ => $v_0 = Nc$
- if $P > P_{max}$ => $v(P) + Pv'(P) = 0$

➢ **Price of the Anarchy (*PoA*)**
- Evaluate the price for not having a social planner in the network (the price for uncoordination in the network)

$$\begin{cases} v(P^*) = -\dfrac{P^*}{N} v'(P^*) \\ v(P^{**}) = -P^{**} v'(P^{**}) \end{cases} \Rightarrow \frac{P^{**}}{P^*} < 1$$

Particular case: $v(P) = a - P^2 \Rightarrow \dfrac{P^{**}}{P^*} \approx \sqrt{\dfrac{1}{3}}$

➢ $PoA = \dfrac{p_i^{**} v(P^{**})}{p_i^* v(P^*)}$;

➢ ***Particular case:*** $v(P) = a - P^2 \Rightarrow PoA = N\left(\dfrac{2+N}{aN}\right)^{\frac{3}{2}}$;

➢When the number of ASes grows to infinity, the Nash equilibrium moves further away from the social welfare

➢When $N \to \infty$ then $PoA \to \infty$

➢Introduce ***payments*** (x_i) to *internalize* the costs and move the Nash equilibrium closer to the Social Optimum

$$x_i = -\sum_{j \neq i} p_j \frac{d}{dp_i} v(P) \Rightarrow x_i = -(P^{**} - p_i^{**}) v'(P^{**})$$

$$u_i(p_i, p_{-i}) = p_i v(P) - Pc - p_i x_i$$

- The *Nash Equilibrium* is the previous *Social Welfare*
- Implemented as
  - ***Tax***
  - ***Pricing mechanism***

References

[1] T. Bu, L. Gao, and D. Towsley, "On characterizing BGP routing table growth," *Computer Networks vol. 45, no. 1, pp. 45–54, 2004.*
[2] X. Meng, Z. Xu, B. Zhang, G. Huston, S. Lu, and L. Zhang, "IPv4 address allocation and the BGP routing table evolution," *SIGCOMM Comput. Commun. Rev., vol. 35, no. 1, pp. 71–80, 2005.*
[3] G. Huston, "Analyzing the Internet BGP Routing Table," *The Internet Protocol Journal, vol. 4, no. 1, 2001.*
[4] K. Fall and P. B. Godfrey, "Routing Tables: Is Smaller Really Much Better?" in *HotNets-VIII, October 2009.*
[5] L. Cittadini, W. Mhlbauer, and S. Uhlig, "Evolution of Internet Address Space Deaggregation: Myths and Reality," *IEEE Journal on Selected Areas in Communications, special issue on Internet Routing Scalability,*. 2010.
[6] Y. Rekhter, P. Resnick, and S. Bellovin, "Financial Incentives for Route Aggregation and Efficient Address Utilization in the Internet,"in *Coordinating the Internet. MIT Press., 1996.*
[7] G. Hardin, "The Tragedy of the Commons," *Science*, vol. 162, pp. 1243–1248, December 1968.
[8] R. Gibbons, *A Primer in Game Theory. Pearson Education, 2001.*
[9] C. Papadimitriou, "Algorithms, games, and the internet," in *STOC '01:Proceedings of the thirty-third annual ACM symposium on Theory of computing, 2001, pp. 749–753.*
[10] T. Roughgarden, "Intrinsic robustness of the price of anarchy," in *STOC '09: Proceedings of the 41st annual ACM symposium on Theory of Computing, 2009, pp. 513–522.*