Theoretic Performance Analysis of Cable Networks with Strategic Subscribers

Haihong Gao

Dept. of Electrical Engineering and Computer Science
Wichita State University
Wichita, KS USA

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Motivations

- In cable networks under flat pricing, light users must subsidize heavy users, and heavy users can cause severe network congestion
- At least in theory, network participants are able to modify standard protocols resulting in security concerns

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Phases of Research

- This paper is the first phase of our research. It is intended to show theoretically the problems of subsidization and congestion in cable networks under a flat pricing scheme
- The second & third phases will provide a solution to the problems raised in this paper

Contributions

- Propose a cable network model from the perspective of control & game theories
- Provide rigorous theoretic proofs for the problems of subsidization and congestion in cable networks under a flat pricing scheme

Scope

- Upstream transmission contention resolution in cable networks

Assumptions regarding DOSCIS

- Only one service type, Best Effort, is configured
- The multiple transmit channel mode is disabled
- The size of an upstream data packet is fixed, and one packet perfectly fits into a single cable network frame
- One bandwidth request is for one data packet, and each MAP contains only one contention request opportunity
- There is no piggyback request

Assumptions regarding CMs

- All agents are rational and strategic
- Each subscriber pays the same constant flat service charge rate
- At each stage, the number of subscribers is fixed

9-Tuple Multi-stage Cable Network Model

$CN = \{CM, T, I, P, A, S, U, F, sw_{cn}\}$

- CM is a **set of CMs**. $CM = \{CM_1, CM_2, ..., CM_n\}$. n is the number of CMs in the cable network system
- T is a **set of stages**. $T = \{t_1, t_2, ..., t_m\}$
- I is a set of **interaction rules**
- P is a set of **policies** for the cable network
- $A = (A_1 \times A_2 \times ... \times A_n)$ is an **action space**. A_i is a set of actions (strategies) of CM_i

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9-Tuple Multi-stage Cable Network Model (Continued)

- $S = (S_1 \times S_2 \times \ldots \times S_n)$ is a **state space**. $S_i = [0, 1]$ is a set of normalized states of CM_i. $s_i: A_i \times A_{-i} \times I \times P \times T \rightarrow S_i$. $A_{-i} = (A_1 \times A_2 \times \ldots \times A_{i-1} \times A_{i+1} \times \ldots \times A_n)$. S_i is used to characterize system microscopic behaviors
- U is a set of **utility functions** of CMs. $U = \{u_1, u_2, \ldots, u_n\}$ and $u_i: S_i \rightarrow \Re$, $u_i \geq 0$, $u_i(0) = 0$, u_i is increasing and concave
- F is a set of nonnegative **social welfare** (SW) measurement functions of the cable network. $F = \{sw_1, sw_2, \ldots, sw_L\}$
- sw_{cn} is a real-valued **aggregated social welfare**, forming an aggregate of the social welfare function measurement vector {sw1, sw2, ..., sw_L}

State Variables

- **Microstates**: the states of CMs. The state of CM_i, s_i, is defined as CM_i's percentage share of the bandwidth. A state vector of CM states, $\{s_1, s_2, ..., s_n\}$, is called an allocation
- **Macrostates** (system states): social welfare functions. The utilitarian and egalitarian are two examples. The utilization is a special case of utilitarian social welfare

Models of Decision Makers

- A social agency maximizes the aggregated welfare of the cable network by providing the network policy

$$p_{\max} = \arg\max_{p \in P} sw_{cn}(sw_1(p), sw_2(p), \ldots, sw_L(p))$$

- An individual subscriber maximizes his/her utility

$$a_{i\max} = \arg\max_{a_i \in A_i} u_i(s_i(a_i, a_{-i}, r, p))$$

Performance Analysis: Two Scenarios

- Cable networks with obeying or disobeying CMs
- Cable networks with heavy and light users

Properties of Cable Networks with Obeying or Disobeying CMs

- All action profiles except the prescribed action profile are Nash equilibriums
- Social welfares of the classes of action profiles:

Profile class	USW	ESW	NE?
AP1	$n*u_{i[allobey]}$	$u_{i[allobey]}$	No
AP2	$u_{i[disobey]}$	0	Yes
AP3		0	Yes

- $u_{i[disobey]} > u_{i[allobey]}$
- AP1- all CMs obey
- AP2- only one CM, CM_i, disobeys & the rest obeys
- AP3- two or more CMs disobey

Properties of Cable Networks with Heavy & Light Users

- The action profile, in which all heavy users use Heavy Use strategy, is the Nash equilibrium
- At equilibrium heavy users subsidize light users ($s_{heq} > s_{leq}$)
- At equilibrium, when the number of heavy users grows, the network utilization $allocsum_{eq}$ approaches zero

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Next Work

- Traffic classification and observer design for cable networks
- Controller design for cable networks
- These two pieces of work together provide a solution to the problems discussed in this paper