Game Theoretic Model for Cluster-based Content Distribution in Vehicular Networks

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***Abstract*—Peer-to-peer based cooperative schemes significantly improved the efficiency of content downloading in vehicular networks. However, uncooperative behavior of peers can severely degrade the system performance, e.g. some vehicles may avoid downloading original data chunks to save the cost of 3G connection, and choose to be a free-rider. On the other hand, if too many nodes connect to the 3G/LTE, the 3G/LTE network may encounter serious congestion, and it would be a waste of network resource if many of them are actually downloading the same content. Faced with such dilemma, we propose a cluster-based content downloading scheme and model it with game theoretic tools. By analyzing the utilities of the game, we conclude that the Nash Equilibrium changes over different network parameters, such as packet loss rate, number of cluster heads, etc.**

I. Introduction and Problem Description

Content downloading in vehicular networks is increasingly popular and demands for better performance due to existing difficulties and challenges including: limited RSUs available on the road, expensive and limited 3G/LTE resource, etc. By introducing the idea of peer-to-peer content delivery to vehicular networks, cooperative schemes, such as SPAWN [1], significantly improve the efficiency of content downloading in vehicular networks, where the cooperation among vehicles is essential to establish such systems. Hence, uncooperative behavior of peers can severely degrade the system performance, e.g. some vehicles may avoid downloading original data chunks through 3G network in order to save the cost of 3G connection, and only wait for other peers to share with him, i.e. choose to be a free-rider.

Incentive design for peer-to-peer file sharing systems have been widely investigated with game theoretic tools, however few has tried to optimize the perform, and almost none considered the dynamic alternation of network condition, which is especially important in highly mobile systems like vehicular networks. In our model, we treat network parameters as variables and discuss the optimization of the game under different situations.

II. System model

A. Network model

We consider vehicular networks where vehicles with the same interested contents form a cluster. A few cluster heads are selected and download the original data contents from the Internet source via 3G/LTE network. The cluster heads share their data packets with other vehicles in the cluster, and others may share with each other in a peer-to-peer fashion. Since the highly mobile vehicular network usually has a significant packet loss rate, in order to cope with the link loss, the cluster heads should perform network coding (with or without redundancy added) before broadcasting the data. A vehicle may receive network coded packets from different cluster heads, but still can decode and reconstruct the original content, similar to the way how a classical multi-path network coding scheme works.

B. Game setting

We model the cluster-based content downloading and peer-to-peer distribution of each network coding generation as a one-shot cluster game $G = (\mathcal{V}, \mathcal{A}, u)$. $\mathcal{V} = \{v_1, ..., v_M\}$ is the set of players, i.e. the set of vehicles in a cluster, where M denotes the total number of vehicles in a cluster, and we will use m to denote the number of cluster heads. $\mathcal{A} = \{Head, Edge\}$ is the set of actions that nodes can take, i.e. chooses to be either a cluster head or an edge node. The utilities of players are shown in Table.I. We assume each node receives a constant benefit of b for receiving each packet. The cluster head nodes encounter a constant cost of c for downloading each packet using 3G/LTE connection. Since energy is not a critical issue for vehicles, here we do not take into account the cost of performing network coding and broadcasting. Let p denote the link loss rate, K denote the network coding generation size, n/K denote the NC redundancy rate, and r denote the number of packets actually received. The utility of being a cluster head, u_H, or being an edge node, u_E, can be formulated as follows:

$$u_H = Kb - Kc \tag{1}$$
$$u_E = Kb \cdot P(r \geq K) \tag{2}$$

where

$$P(r \geq K) = \sum_{r=K}^{mn} \binom{mn}{r} (1-p)^r p^{(mn-r)}$$

Here $P(r \geq K)$ is the probability that an edge node receives enough encoded packets (at least K) to decode. If a node receives less than K packets for a generation, it cannot decode and receives 0 utility. The number of packets received follows a binomial distribution $B(mn, 1-p)$.

		$\{v_{-i}\}$ Head	Edge
v_i	Head	(u_H, u_H)	(u_H, u_E)
	Edge	(u_E, u_H)	(0,0)

TABLE I
THE UTILITY MATRIX OF ONE-SHOT CLUSTER GAME

C. Game analysis

In order to analyze the cluster game including computing the Nash Equilibrium, we need to know which is larger between u_H and u_E. Given a fixed set of NC generation size K, redundancy rate n/K, benefit and cost scalers b and c, according to (1), u_H is a constant, i.e. a cluster head always has a fixed utility for downloading packets from LTE. According to (2), u_E is a function that varies over two parameters: V2V link loss rate p and the number of cluster heads m. Fig.1 and Fig.2 show how u_E varies over different link loss rate p and number of cluster heads m, comparing to u_H. We can see for most cases where link loss rate is acceptable and there is at least one cluster head, the utility of being an edge node is almost twice as much as being a cluster head, i.e. $u_E \simeq 2u_H$, assuming the cost benefit ratio c/b is 0.5. Only when the V2V link loss rate is so high that almost no packets can get through, the utility of being a cluster head could be higher than being an edge node. One special case is that nobody is willing to be cluster head, and everyone receives 0 utility as a consequence of uncooperative behavior.

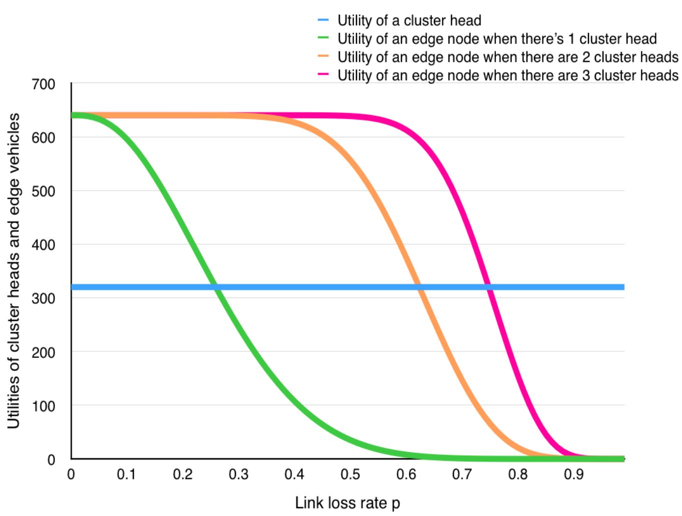

Fig. 1. How utility varies over different link loss rate. Settings: $K = 8$; $n = 10$; $M = 100$; $b = 80$; $c = 40$

For this game, when $u_H \geq u_E$, there is one Nash Equilibrium: (Head, Head). Practically it refers to the situation where all nodes connect to the 3G/LTE and download data by themselves when V2V communication is not available. In this case we do not need to worry about uncooperative behavior because cooperation is not an option. When $u_H \leq u_E$, there are two Nash Equilibriums: (Head, Edge) and (Edge, Head), which already select the action that maximizes the total utility. However, if we think practically, the Nash Equilibrium cannot be efficiently achieved without the help of an incentive

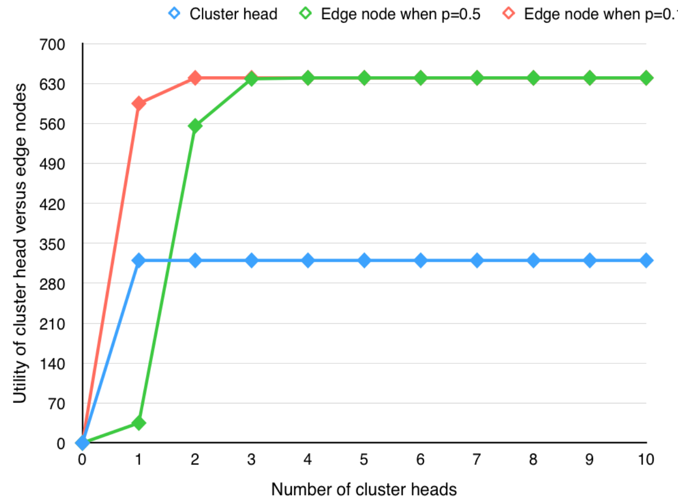

Fig. 2. How utility varies over different number of cluster heads. Settings: $K = 8$; $n = 10$; $M = 100$; $b = 80$; $c = 40$

compatible scheduling mechanism. If we assume nodes take actions all at the same time without knowing others' selection, they would select the action that maximize the expected utility, i.e. being an edge node, and finally everyone chooses to be an edge node; if we assume nodes choose action one by one, and the later ones can observe what the others have chosen, then the Nash Equilibrium will be finally achieved when everyone chooses to be an edge node until the last one who has to be the only cluster head, which is unfair and inefficient. Therefore in both assumptions, the cluster-based scheme cannot work fairly and efficiently without a scheduling system, and it must be an incentive compatible one that selfish nodes would be willing to follow the rule. We already begun our work on a reputation based incentive compatible scheduling system, and optimize the system setting by tuning the design parameters.

III. Conclusions

Content downloading and distribution by forming a cooperative cluster of vehicles largely reduce the traffic load of 3G/LTE network and the cost of 3G/LTE connection of individual vehicles. The efficient cooperation of selfish individuals needs to be enforced by incentive compatible scheduling schemes. This extended abstract proposes an efficient cluster-based content distribution scheme for vehicular networks, and models the system with games. By analyzing the game, we show that the utilities vary over different networks parameters, e.g. link loss rate, and the settings of the cluster, e.g. the number of cluster heads. As future work, we will present a reputation based incentive compatible scheduling scheme and optimize it by tuning the design parameters.

References

[1] A. Nandan, S. Das, G. Pau, M. Gerla, and M. Sanadidi. Co-operative downloading in vehicular ad-hoc wireless networks. In *Wireless On-demand Network Systems and Services, 2005. WONS 2005. Second Annual Conference on*, pages 32–41, 2005.