A Signaling Game-based Mechanism to Meet Always Best Connected Service in VANETs

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***Abstract*—In heterogeneous network environments, users need to have mechanisms in place to decide which network is the most suitable at each moment in time for every application that the user requires. Always Best Connected is considered as a special concept to allow users to get connected to Internet using the access technology that best suits their needs or profile at any point in time. Clearly, this concept provides multiple access simultaneously for mobile users moving in heterogeneous access network environment. In this paper, we introduce a signaling game approach to achieve an always best connected service in vehicular networks. Under the considered scenario, we consider two smart vehicles named player 1 and player 2 moving in a road network area equipped with heterogeneous access networks. We assume that player 1 (super player) only has complete information on the road network, whilst player 2 has not any information. Player 1 plays first and sends a signal to player 2 which can be accurate or distorted. Based on the received signal and his belief about that signal, player 2 chooses its own action: it computes its suitable path which provides it an always best connected service.**

***Index Terms*—Always Best Connected, Access technologies, Heterogeneous networks, Signaling game, Complete information, Partial information, Accurate signal, distorted signal, Belief**

I. INTRODUCTION

Currently, most mobile devices come with various network interfaces. The smart cars become equipped with multi-radio interfaces. Even the cheaper smart phones support at least two wireless technologies, for example the Universal Mobile Telecommunications System (UMTS) and IEEE 802.11 (WLAN). Thanks to these devices, the number of heterogeneous access networks that are available at a specific location grew dramatically. All of these networks show different communication characteristics, e.g. in terms of throughput, delay, availability and costs, and in combination they offer a high communication performance.

Furthermore, the diversity of wireless networks provides multiple Internet access for users whose terminals are equipped with multi-radio interfaces. Such users expect to select best access network to enjoy their multimedia applications with their subscribed Quality of Service (QoS). In an environment of multiple access technologies, the goal is not only to being always connected, but also to being always best connected [1]. This concept which is called Always Best Connected (ABC) allows a user in an environment of multiple access technologies to connect at Internet services using the access technologies that best suit to his needs at any point in time. In order to realize this concept, several technologies must be addressed by forming a heterogeneous networks environment. Each mobile user in such environment wants to be connected to the best, anywhere, anytime and with any network access. For this reason, the different wireless technologies must coexist so that the best technology can be adopted depending on the user's profile, on the type of application and on the service which he needs. Moreover, thanks to the proliferation of the vehicular intelligent devices, vehicle to roadside communication has received considerable attention. With Roadside access technology, vehicles can exchange (download/upload) data with the multiple access technologies installed in fixed locations along the road in order to enjoy a large number of applications including local electronic advertisement, intelligent transportation system and environment data collection. Fig. 1 shows an example of multi-access technologies for Vehicular Ad-hoc Network (VANET).

Fig. 1. Multiple access technologies for VANET

In wireless networks, the signal is considered as a special sort of physical interaction between nodes. It represents the product of a strategic dynamic between sender and receiver so that each of whom is pursuing distinct but interrelated objectives. Moreover, a signal is a specific type of strategic interaction in which the content of this interaction is determined by the sender, and it changes the receiver's behavior by altering the way the receiver evaluates alternative actions. This situation type is called a signaling game theory [2], which

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is known in the literature as "Cheap Talk": the sender incurs no cost for his signals.

In this paper, we use the signaling game theory to study the problem of providing ABC for vehicles passing a geographical area equipped with heterogeneous networks as WiFi, HiperLan, Bluetooth, etc. Its goal is to satisfy the needs (achieving ABC service) of each vehicle passing the coverage region while maximizing the expectation of its own utility.

The remainder of the paper is structured as follows. Section II presents related work. In Section III we introduce the signaling game model that we consider in this paper. Numerical results are presented and discussed in Section IV. Finally we conclude the paper in Section V.

II. RELATED WORK

In heterogeneous network environment, the technologies act as multi-access points to internet for users. Several researches are developed so that these users can be always best connected. For example, in [3] the concept and the architecture of an always best connected scenario are described. Sharma et al. [4] proposed a vertical hand off system between WLAN and GPRS links by using an extension of the Mobile IP protocol. While [5] intends to achieve ABC over WLAN and WiMAX by using a new mechanism to detect QoS support of the underlying networks. In [6], a cost function is defined over some networks characteristics such as RSS (Received Signal Strength), preferred access network type, QoS requirements of applications, monetary cost of services, and power consumption in order to choose a suitable network. In addition to the factors cited above, [7] and [8] also consider user preferences to select the access network that is more flexible. In our previous works, we have introduced the ABC concept in VANETs. In [9] and [10], we proposed two fully-decentralized algorithms to select an access network for Group Vertical HandOver (GVHO) in Heterogeneous Networks. Whilst in [11], we proposed an algorithm to compute the path which provides an ABC service for a smart vehicle moving in a road network installed with multiple access technologies. Furthermore, signaling game theory has been also applied to study several problems in wireless networks. For example, in [12], The authors proposed an intrusion detection game based on the signaling game theory. In [13], a recent work is proposed to study the problem of power control in wireless networks by applying the signaling game approach. The authors in [14] applied the signaling game approach to study two competition problems between service providers with asymmetric information.

The main novelty of this paper is the use of signaling game theory for studying the problem of achieving always best connected service in VANET. According to the best of our knowledge, this work has not been done before. Specifically, we consider a situation where players (vehicles) compete to maximize the expectation of their own utility in order to find the suitable path which provides them always best connected service. We assume that the quality of technologies installed in the road network area takes two values: high or low. To simplify the problem, we will focus our study on the case of two players namely, player 1 and player 2. We further assume that player 1 is the only one who is informed about the different technologies installed in the road network area. Based on this information, player 1 sends a signal to the uninformed player, i.e. player 2. Since player 2 receives the signal it takes its own decision and computes the optimal path which provides it the always best connected service.

III. THE SIGNALING GAME MODEL

A. Game Model Description

Considering a road network area A which is constituted by edges and nodes. This area is modeled by a connected directed graph G, whose vertex set $V(G)$ corresponds to the set of nodes. Its edge set $E(G)$ corresponds to the set of mobility links between nodes on which vehicles travel. There exists a mobility link between two neighboring nodes i and j only if a vehicle can travel from node i to node j immediately. In this area, access technologies are installed along the edges and provide access Internet to vehicles moving in this area. Each vehicle i can travel from point source S_i to point destination D_i via several paths. Our model aims to compute the path which provides an always best connected service for each vehicle in context of partial information. The choice of this path depends on the technologies characteristics in terms of throughput, communication range, network coverage, etc.

In the proposed model, player 1 is the only one who knows the quality of the technologies installed in the road network. It moves first and sends a signal to player 2 in order to inform it about these technologies. This signal can be accurate or distorted. Moreover, The received signal can be believed as an accurate signal or not believed by player 2. Based on this signal and his belief, player 2 computes the suitable path which provides an always best connected service.

B. The Game Scenario

In order to simplify the proposed system, let us present the following scenario in which we consider the case of two vehicles (which we call players).

- The quality q_e of an access technology installed in an edge e can take two values: high (q_h) or low (q_l).
- The value of q_e is generated according to a probability distribution p. It equals q_h with probability p_e and q_l with probability $(1 - p_e)$.
- Only player 1 knows the quality of technologies installed in the road network.
- Player 1 observes the quality q_e and then sends a signal $\xi(e, q_e)$ to player 2. It signals $\xi(e, q_h)$ if it observes q_h and signals $\xi(e, q_l)$ if it observes q_l. We assume that: $\xi : E \times \{q_h, q_l\} \longrightarrow \{q_h, q_l\}$.
- The degree's belief of player 2 about the received signal $\xi(e, qe)$ is $\beta_e \in [0, 1]$.
- Based on the received signal and his belief, player 2 computes the suitable path ℓ from S to D.

We assume that probabilities p_e and β_e are common knowledge for both players.

C. The Utility Function

The goal of this work is to find the ABC path which provides an always best connected service for each vehicle moving in a road network area equipped with multi-access technologies. The utility function of both players depends on the signal $\xi(e, q_e)$ generated by first player and on the path of second player ℓ. The path ℓ is constituted by a set of edges e.

Let $|E|$ and $|\ell|$ denote the total length of edges in the road network area and the total length of edges that constitute the path ℓ, respectively. And d_e denotes the length of an edge e. The utility function for each player is given as follows.

$$\begin{aligned} U^1 &= U^1(\xi, \ell) \\ &= \mathbb{E}_p[\frac{1}{|E|}\sum_{e\in E}\frac{d_e q_e}{n_e(\ell)}] \\ &= \frac{1}{|E|}\sum_{e\in E}\frac{d_e(p_e q_h + (1-p_e)q_l)}{n_e(\ell)} \end{aligned}$$

$$\begin{aligned} U^2 &= U^2(\xi, \ell) \\ &= \mathbb{E}_p[\frac{1}{|\ell|}\sum_{e\in \ell}\frac{d_e(\beta_e \xi(e,q_e) + (1-\beta_e)\xi^c(e,q_e))}{n_e(\ell)}] \\ &= \frac{1}{|\ell|}\sum_{e\in \ell}\frac{d_e(\beta_e \mathbb{E}_p[\xi(e,q_e)] + (1-\beta_e)\mathbb{E}_p[\xi^c(e,q_e))]}{n_e(\ell)} \\ &= \frac{1}{|\ell|}\sum_{e\in \ell}[\frac{d_e(\beta_e(p_e\xi(e,q_h) + (1-p_e)\xi(e,q_l))}{n_e(\ell)} \\ &+ \frac{d_e((1-\beta_e)(p_e\xi^c(e,q_h) + (1-p_e)\xi^c(e,q_l))}{n_e(\ell)}] \end{aligned}$$

where $\mathbb{E}_p$ is mathematical expectation in probability distribution p and:

$$\xi^c(e,q_e) = \begin{cases} q_h, & \text{if } \xi(e,q_e) = q_l \\ q_l, & \text{if } \xi(e,q_e) = q_h \end{cases}$$

$$n_e(\ell) = \begin{cases} 2, & \text{if } e \in \ell \\ 1, & \text{else} \end{cases}$$

It equals 2 to take into account the interaction between both players when they meet in the same edge and equals 1 otherwise. To simplify, we assume for all edges $e \in E$:

$$\beta_e = \beta \text{ and } \xi(e,q_e) = \eta(q_e)$$

Thus we can rewrite:

$$U^1 = \frac{1}{|E|}\sum_{e\in E}\frac{d_e(p_e q_h + (1-p_e)q_l)}{n_e(\ell)}$$

$$\begin{aligned} U^2 &= \frac{1}{|\ell|}\sum_{e\in \ell}[\frac{d_e(\beta(p_e\eta(q_h) + (1-p_e)\eta(q_l))}{n_e(\ell)} \\ &+ \frac{d_e((1-\beta)(p_e\eta^c(q_h) + (1-p_e)\eta^c(q_l))}{n_e(\ell)}] \end{aligned}$$

Each player responds by a best strategy in order to maximize the expectation of its own utility. The strategies space for each player is given by:

- $S_1 = \{\eta, \quad \eta : \{q_h, q_l\} \longrightarrow \{q_h, q_l\}\}$
- $S_2 = \{\ell, \quad \ell : \text{is a path from } S \text{ to } D \text{ in road network}\}$

D. Equilibrium Strategies

We recall that player 1 sends a signal η to player 2 who uses this signal to compute its suitable path ℓ. At equilibrium, player 2 responds by a strategy ℓ^* that maximizes its expected utility. The Nash equilibrium for such a game is a pair of strategies (η^*, ℓ^*) such that each player uses the best response in a non-cooperative way. Formally, the equilibrium point (η^*, ℓ^*) in the game is computed as follows:

- $\eta^* \in \underset{\eta\in S_1}{argmax}\ U^1(\eta, \ell^*)$
- $\ell^* \in \underset{\ell\in S_2}{argmax}\ U^2(\eta^*, \ell)$

Theorem: The proposed game admits a Nash equilibrium.

Proof: Since S_1 and S_2 are finite spaces, then there exists a pair of strategies $(\eta^*, \ell^*(\eta))$ such that:

- $\ell^*(\eta) \in \underset{\ell\in S_2}{argmax}\ U^2(\eta^*, \ell)$
- $\eta^* \in \underset{\eta\in S_1}{argmax}\ U^1(\eta, \ell^*(\eta))$

Thus according to the above definition, $(\eta^*, \ell^*(\eta^*))$ is a Nash equilibrium of the proposed game because:

- $U^2(\eta^*, \ell^*(\eta^*)) \geq U^2(\eta^*, \ell(\eta)), \quad \forall \ell \in S_2$
- $U^1(\eta^*, \ell^*(\eta^*)) = U^1(\eta, \ell^*(\eta^*)), \quad \forall \eta \in S_1$

E. Computing Nash Equilibrium

Because of the numerical complexity to evaluate all paths from source S to destination D, we propose the following algorithm which is based on *Dijkstra's algorithm* [15] to compute the suitable path according to a received signal $\tilde{\eta^*}$. We associate a quality $\tilde{q_e}$ then a cost c_e to each edge e and we compute the suitable path $\tilde{\ell^*}$ that provides ABC service to the player 2. Thus, the Nash equilibrium for such game is the pair of strategies $(\tilde{\eta^*}, \tilde{\ell^*})$.

Algorithm: *The best response $\tilde{\ell^*}$ of player 2*

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Input:
    • The road network graph $G = (V, E)$
    • The signal $\eta$
    • The probability $p_e$, $\beta$
    • The source $S$ and destination $D$
Output: The ABC path $\tilde{\ell^*}$ from $S$ to $D$
For each edge $e$ do:
    1. Compute the quality $\tilde{q_e}$:
        $\tilde{q_e} = \frac{1}{2}[\beta(p_e\eta(q_h) + (1-p_e)\eta(q_l))$
            $+(1-\beta)(p_e\eta^c(q_h) + (1-p_e)\eta^c(q_l))]$
    2. Compute the cost $c_e$:
        $c_e = d_e(q_h - \tilde{q_e})$
End For
    • Apply Dijkstra's algorithm on $G = (V, E)$
    • Return the suitable path $\tilde{\ell^*}$ from $S$ to $D$
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Theorem: The path $\tilde{\ell^*}$ which is computed in the above algorithm is the best response of player 2 according to the received signal η.

Proof: Let $\ell \in S_2$ is a path from source S to destination D.

- **Case** $|\ell| \geq |\tilde{\ell^*}|$:
  we have $\sum\limits_{e' \in \ell} (q_h - \tilde{q'_e}) \geq \sum\limits_{e \in \tilde{\ell^*}} (q_h - \tilde{q_e})$
  then $\sum\limits_{e' \in \ell} (\tilde{q'_e} - q_h) \leq \sum\limits_{e \in \tilde{\ell^*}} (\tilde{q_e} - q_h)$
  using the inequality $\frac{1}{|\ell|} \leq \frac{1}{|\tilde{\ell^*}|}$
  we obtain $\frac{1}{|\ell|} \sum\limits_{e' \in \ell} (\tilde{q'_e} - q_h) \leq \frac{1}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} (\tilde{q_e} - q_h)$
  then $\frac{1}{|\ell|} \sum\limits_{e' \in \ell} \tilde{q'_e} \leq \frac{1}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} \tilde{q_e}$
  Thus:
  $$U^2(\eta, \ell) \leq U^2(\eta, \tilde{\ell^*}) \tag{1}$$
- **Case** $|\ell| \leq |\tilde{\ell^*}|$:
  we assume that $U^2(\eta, \ell) > U^2(\eta, \ell^*)$
  we have then $\frac{1}{|\ell|} \sum\limits_{e' \in \ell} \tilde{q'_e} > \frac{1}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} \tilde{q_e}$
  therefor $q_h - \frac{1}{|\ell|} \sum\limits_{e' \in \ell} \tilde{q'_e} < q_h - \frac{1}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} \tilde{q_e}$
  so $\frac{1}{|\ell|} \sum\limits_{e' \in \ell} (\tilde{q'_e} - q_h) < \frac{1}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} (\tilde{q_e} - q_h)$
  by signification $\sum\limits_{e' \in \ell} (\tilde{q'_e} - q_h) < \frac{|\ell|}{|\tilde{\ell^*}|} \sum\limits_{e \in \tilde{\ell^*}} (\tilde{q_e} - q_h)$
  then $\sum\limits_{e' \in \ell} (\tilde{q'_e} - q_h) < \sum\limits_{e \in \tilde{\ell^*}} (\tilde{q_e} - q_h)$ because $\frac{|\ell|}{|\tilde{\ell^*}|} \leq 1$
  Thus:
  $$U^2(\eta, \ell) \leq U^2(\eta, \tilde{\ell^*}) \tag{2}$$
  Then from (1) and (2) we conclude that:
  $$U^2(\eta, \ell) \leq U^2(\eta, \tilde{\ell^*}), \forall \ell \in E$$

So, the path $\tilde{\ell^*}$ is the best response of player 2 according to the received signal η.

IV. NUMERICAL RESULTS

Now we consider the following parameters for all simulation results: $q_h = 54$ Mbit/s, $q_l = 3$ Mbit/s, $p \in [0, 1]$, $\beta \in [0, 1]$. The probability p_e to have high quality in edge e is generated as a random value between 0 and p.

A. Impact of Belief's Degree on the Signal Type

Under the proposed scenario and the applied game, each player wishes to maximize its own utility in a non-cooperative way. Player 1 moves first and sends a signal which is accurate or distorted. Player 2 receives this signal with a degree of belief β and computes the path which provides it always best connected service. Fig. 2 shows the percentage of accurate signal in function of belief's degree. When the second player does not believe in the received signal ($\beta \leq 0.5$), the first player often sends an accurate signal (the percentage of accurate signal exceeds 90%). Otherwise, once the second player believes in the signal ($\beta \gg 0.5$), the percentage of accurate signal decreases with the increasing of belief's degree β, until it reaches its minimum ($\approx 60\%$) where β is close to 1. This can be explained by the fact that the first player tries to delude the second player in order to maximize its own utility in a non-cooperative way.

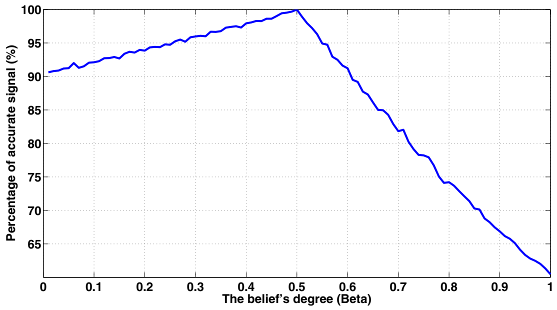

Fig. 2. The percentage of accurate signal as function of the degree of belief

B. Impact of Belief's Degree on Utilities

Using box plot, we present in Fig. 3 and Fig. 4 the expected utility distribution of both players at equilibrium as function of the belief's degree about the received signal. In the simulation we set the probability distribution p to 0.8 and we compute the dispersion of expected utility for each value of $\beta \in [0, 1]$. According to the simulation results obtained, the first player's utility is relatively dispersed around the median which is almost stable as function of β. But the second player's utility becomes stable and reaches its minimum when β is close to 0.5, and more dispersed around the median otherwise.

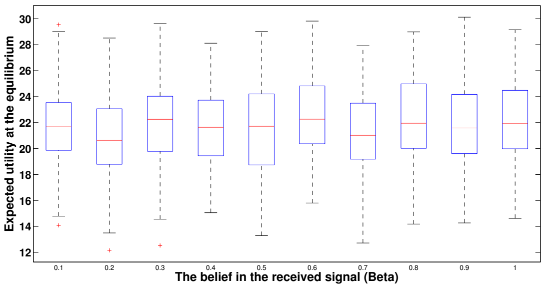

Fig. 3. The expected utility distribution of first player at the equilibrium as function of the belief in the received signal with $p = 0.8$

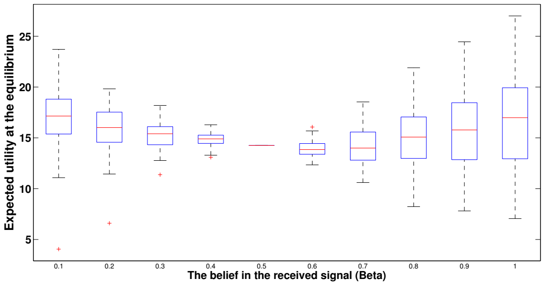

Fig. 4. The expected utility distribution of second player at the equilibrium as function of the belief in the received signal with $p = 0.8$

Moreover, as depicted in Fig. 5, at low values of probability distribution of access technologies installed in the road network ($p = 0.2$), the second player's utility decreases with increasing of belief's degree in the received signal, whilst the first player's utility stays almost stable in function of β. This is due to the fact that the first player is often based on access technologies quality to compute its utility, whereas the second player is often based on its belief in the received signal.

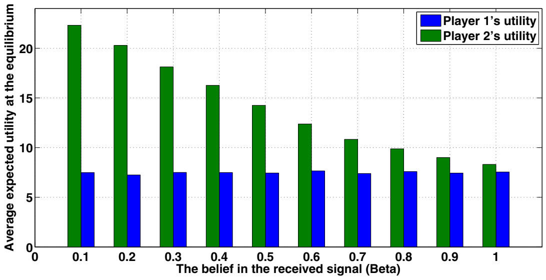

Fig. 5. The average expected utility for each player at the equilibrium as function of the belief in the received signal with $p = 0.2$

C. Impact of Access Technologies Distribution on Utilities

Fig. 6 and Fig. 7 depict the average expected utility of both players in function of the probability distribution of technologies installed in the road network. According to the simulation results, the first player's utility increases with increasing of p whatever the value of β. Whilst, the second player's utility decreases with increasing of p when player 2 does not believe in the received signal ($\beta = 0.1$), and increases (but remains lower) when he believes in it ($\beta = 0.9$).

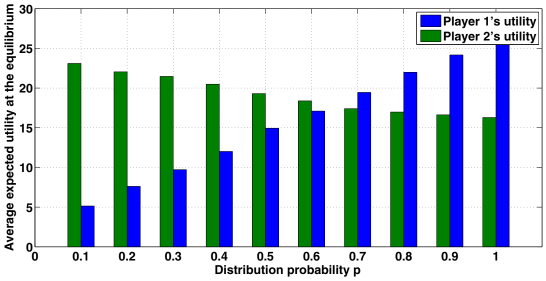

Fig. 6. Average expected utility at the equilibrium as function of the distribution of technologies installed in the road network with $\beta = 0.1$

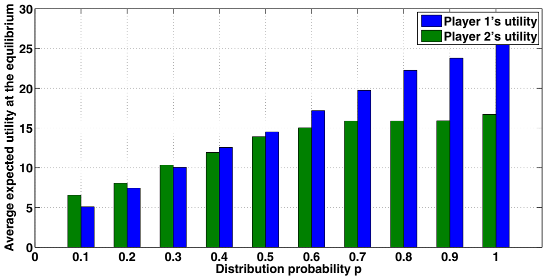

Fig. 7. Average expected utility at the equilibrium as function of the distribution of technologies installed in the road network with $\beta = 0.9$

V. CONCLUSION

In this paper, we have introduced a signaling game approach to provide always best connected service for a smart vehicle moving in a geographical area equipped with heterogeneous access networks. We considered the case of two vehicles (players) aiming at maximizing their own expected utility in a non-cooperative way. According to the simulation results, we conclude that the belief in the received signal does not have a significant impact on first player's utility, whilst it has a considerable impact on that of second player. Moreover, the first player's utility increases with the increasing of the probability distribution of technologies installed in the road network whatever the belief's degree in the received signal. But the second player's utility decreases with the increasing of the probability distribution when he does not believe in the received signal and increases otherwise; knowing that, this utility stays important in the first case compared with that in the second case. As the game is non-cooperative, each player tries to delude the other in order to maximize its own utility.

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