The 4th Workshop of COST Action IC0902
Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks
October 9–11, 2013
Rome, Italy

"Contribution to Special Interest Group 2, Learning and Artificial Intelligence"

Carrier Aggregation as a Repeated Game: Learning Algorithms for Efficient Convergence to a Nash Equilibrium

Hamed Ahmadi, Irene Macaluso, Luiz A. DaSilva
CTVR Telecommunications Research Center, Trinity College Dublin, Ireland
Presenter: Hamed Ahmadi

Introduction and motivation:

Carrier aggregation, as currently envisaged, will involve the aggregation of static assignments of spectrum. However, recent works have explored its extension to dynamic contexts, where carriers are assigned to networks over shorter time frames on an as-needed basis. Dynamic carrier allocation can be achieved in a distributed and uncoordinated manner: networks blindly interact in order to achieve a stable allocation of the available carriers. In our model, each network, which initially exclusively occupies licensed carriers, has to decide how many and which carriers to aggregate from a common pool of spectrum resources. As we assume no exchange of information among the networks, we model the problem of dynamic carrier aggregation as a non-cooperative game and propose learning algorithms that converge to a pure Nash equilibrium (NE) within a reasonable number of iterations under the conditions of incomplete and imperfect information.

The problem posed in this work falls under the umbrella of managing coexistence among a group of networks operating in the same geographical area. The key challenge in managing coexistence is to avoid co-channel and adjacent channel interference. Our work extends the traditional channel selection problem by allowing each network to aggregate non-contiguous channels in multiple frequency bands. Adjacent channel interference has usually been disregarded in previous works on distributed channel selection. Channels are commonly modelled as orthogonal, thus relegating the problem of adjacent channel interference to the physical layer domain. Our model includes the effect of out-of-channel (OOC) interference in adjacent frequency channels. This way we achieve two objectives: we relax the assumption on channel orthogonality, and we are able to model the preference for contiguous channels aggregation. Furthermore, the model proposed in this work also takes into account another important feature of CA. In fact, while allowing both intra- and inter-band CA, we assign a higher cost to the latter on account of the corresponding physical layer requirements.

System model and formulation

Let us assume that N wireless networks ($N=\{1,2,...,N\}$) operate in the same geographical area where B frequency bands ($B=\{1,2,...,B\}$) are available for dynamic usage. Each band has K_b channels and the networks can simultaneously operate on multiple contiguous and non-contiguous channels. Each network is a player in the game that models the problem of dynamic CA. Action a_i denotes the set of channels selected by player i; nbands(a_i) is the number of bands that node i accesses when selecting action a_i (nbands(a_i) $\leq$ $|a_i|$); N_{Bi} is the maximum number of bands that player i can simultaneously use. We define the payoff of player i as:

$$r_i(\boldsymbol{a}) = \begin{cases} \dfrac{1}{M_i} \displaystyle\sum_{c_i \in a_i} \left(1 - \dfrac{\gamma_{c_i}}{\overline{\gamma_i}}\right) - \dfrac{(nbands(a_i) - 1)\delta}{N_{B_i}} & if\ a_i \neq 0 \\ 0 & if\ a_i = 0 \end{cases}$$

where γ_{ci} is the interference measured in channel c_i and normalized in the range [0,1], and δ is a parameter that each network can tune to reflect its degree of flexibility in performing CA. We can formulate the distributed CA problem as a game denoted by $G=(N,A,r)$. In this game, N is the set of players, which are the radio networks, $A = \times A_i$ is the set of their possible actions, and r is the payoff function. We have proven that at least one Nash equilibrium in pure strategies exists in CA game G.

Learning algorithms

In this work we introduce interactive trial and error learning best action (ITEL-BA). This algorithm is proven to converge to a pure NE with a high probability. ITEL-BA can be denoted by a tuple $z_i = (m_i, \overline{a_i}, \overline{r_i})$ for each player, where $\overline{a_i}$ and $\overline{r_i}$ denote the benchmark action and benchmark utility (payoff), respectively. In the ITEL-BA tuple, m_i denotes the player's mood, which can be either *content*, *discontent*, *hopeful*, or *watchful*. The current action and current utility are denoted by a_i and r_i, respectively. Fig. 1 shows the mood transitions in ITEL-BA and the expected total sensing time.

Simulation results

In Fig. 2, we present and compare the probability of convergence to an NE for scenarios where different numbers of ITEL-BA-adopting networks compete for aggregation of channels in different numbers of bands. We analyze the impact of the cardinality of the action space, the number of bands, and the distribution of the available channels on those bands, on the probability of convergence to an NE. These elements, along with the cost associated with inter-band CA, affect the number of pure NE of the CA game. It is important to note that two scenarios characterized by the same number of networks, bands and total number of available channels, exhibit a different number of NE based on the distribution of available channels. As we can observe in Fig. 2, ITEL-BA requires more iterations to converge to an NE with a high probability as the number of networks and/or the cardinality of each player's action space increases.

Figure. 1

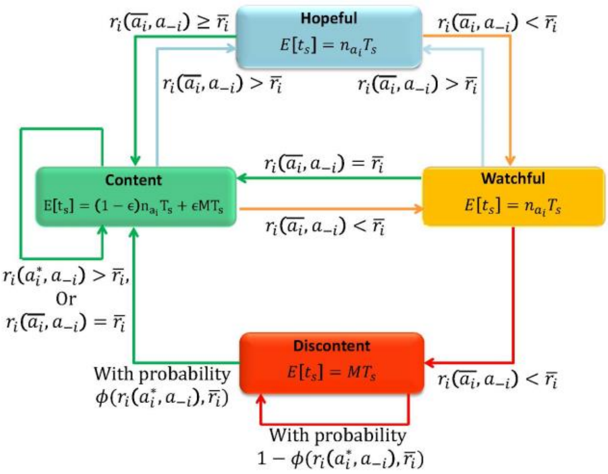

Figure. 2