Towards Business-Oriented Services Communities: A Stackelberg Game Theoretical Model

Omar Abdel Wahab

Concordia University

o_abul@encs.concordia.ca

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Motivation

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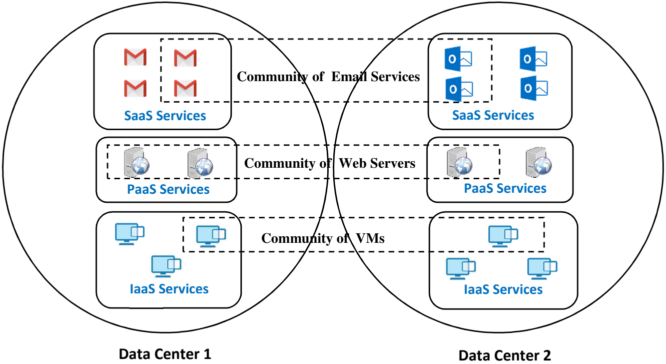


SaaS Services
Community of Email Services
SaaS Services
PaaS Services
Community of Web Servers
PaaS Services
IaaS Services
Community of VMs
IaaS Services
Data Center 1
Data Center 2

Literature Review

(1) User-Centric:

1. **Idea:** Optimize the performance of Web services and thus the user satisfaction.
2. **Limitation:** Ignore intelligent Web services' satisfaction.

(2) Service-Centric:

1. **Idea:** Analyze the objectives of the Web services as rational agents in the process of creating communities.
2. **Limitations:** Assume the pre-existence of a community and community manager/master as result of Service Level Agreement (SLA) and ignore the business potential of the involved services.

Contributions

1. Proposing a distributed formation model for services communities, where all services are totally autonomous in making their decisions.
2. Formulating the problem as a two-stage sequential Stackelberg game model and deriving the equilibrium point analytically.
3. Assuming that services are not equally strong and differentiating between Web services based on to their parameters.

Proposed Solution

Model Architecture

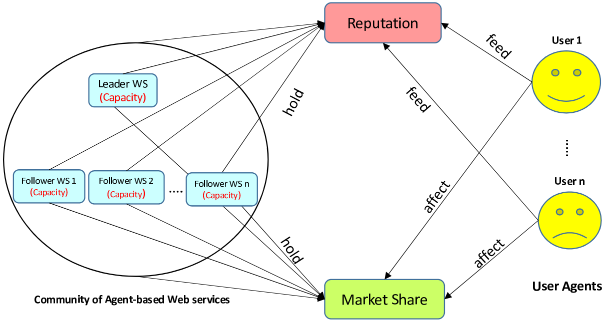
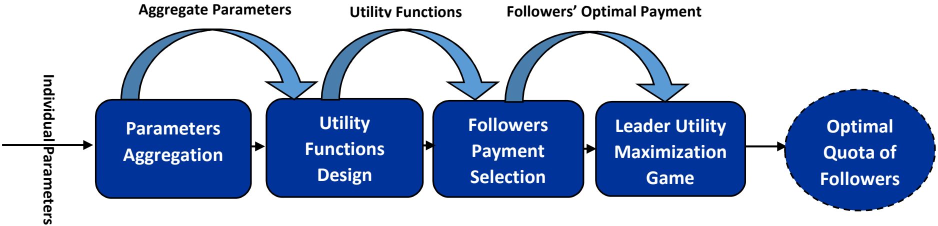


Figure: Model Architecture: Web service agents hold a fixed capacity value and variable reputation and market share values that are affected by the user agents

Proposed Solution



Property 1. f is monotonically increasing for the leader if the gap between R_L and R_F is small.

Property 2. f is strictly decreasing for the leader when the gap between R_L and R_F is big.

Property 3. f is strictly increasing for the followers if the gap between R_L and R_F is small.

Property 4. f is monotonically increasing for the followers if the gap between R_L and R_F is big.

Proposed Solution
Utility Functions

Followers Utility Function:

$$U_F = \frac{P_F}{\sum_{i \in S} P_i}[\Delta(R_L) + \Delta(M_L) + \Delta(C_L)] - P_F, \quad (1)$$

Leaders Utility Function:

$$U_L = \sum_{F \in S}[\Delta(R'_F) + \Delta(M'_F) + \Delta(C'_F) + P_F], \quad (2)$$

Algorithm 1: Followers Payment Selection Game

Input: Pre-selected set of followers S
Input: Leader's reputation R_L
Input: Leader's market share M_L
Input: Leader's capacity C_L
Output: Optimal payment for followers P_F^*
procedure FOLLOWERSPHASE
  for each follower $F \in S$ **do**
    Compute $\Delta(R_L)$
    Compute $\Delta(M_L)$
    Compute $\Delta(C_L)$
    Compute initial payment
    Get information about the payment of all other followers in S
    Compute P_F^*
  end for
end procedure

Theorem 1

$U_F = \frac{P_F}{\sum_{i \in S} P_i}[\Delta(R_L) + \Delta(M_L) + \Delta(C_L)] - P_F$ *is concave down in* P_F

Theorem 2

The equilibrium of the game G *is given by*

$$P_F^* = \sqrt{[\Delta(R_L) + \Delta(M_L) + \Delta(C_L)] \sum_{i \in S, i \neq F} P_i} - \sum_{i \in S, i \neq F} P_i$$

Proposed Solution

Leader's Utility Maximization Game

Algorithm 2: Leader's Utility Maximization Game

```
Input: Quota size |Q|
Input: Optimal payment for followers P*_F
Output: Optimal quota of followers S*
procedure LeaderPhase
    Pre-select a set of followers S
    Publish reputation, market share, and capacity to S
    Repeat
        Enumerate all possible combinations C in S so that |C| = |Q|
        Compute Δ(R_F)
        Compute Δ(M_F)
        Compute Δ(C_F)
        Compute utility U_L(C) based on P*_F
    Until C = arg max_C U_L(C)
    S* = C
end procedure
```

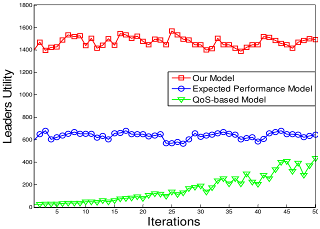
Based on the analytical results of the followers payment selection game, the leader optimizes its strategy by selecting the optimal quota S^* amongst S that maximizes its revenue.

$$U_L = \sum_{i \in S} (\Delta(R_i') + \Delta(M_i') + \Delta(C_i') + [\sqrt{(\Delta(R) + \Delta(M) + \Delta(C)) \sum_{i \in S, i \neq F} P_i} - \sum_{i \in S, i \neq F} P_i]), \quad (3)$$

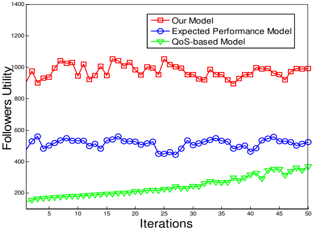
1. The information related to Web services is populated from a real-life dataset that includes 2507 real services operating on the Web.
2. The topic of flight booking has been used for the simulations.
3. Users send XML-based requests containing the flight dates, origin and destination, number of seats, and type of tickets and receive an XML-based response consisting of different flights hosted by different companies along with the related information such as prices and timing.
4. $200,000$ flights are collected and stored in the database that records the values of 9 QoS metrics including throughput, availability, and reliability.

Experimentation and Empirical Analysis

Web Services Agents Satisfaction



(a) Leader Web services Utility



(b) Follower Web services Utility

Experimentation and Empirical Analysis

Impact of Preselected Set Size

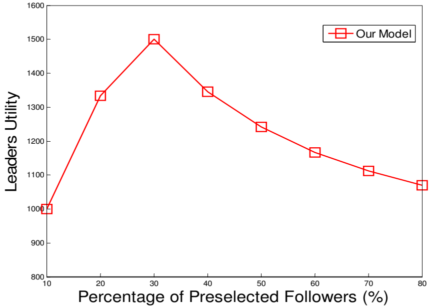


Figure: Preselection size vs. Leaders utility

Conclusion

- This work investigates the problem of distributively forming communities of autonomous Web services among services having uneven business capabilities using a Stackelberg game theoretical model.
- Our work enjoys three main advantages:
  - it considers a fully distributed environment, where all the services are completely autonomous in their decisions;
  - a two-stage sequential Stackelberg game is used to ensure the formation of optimal and stable communities in the long-term.
  - the proposed model outperforms a heuristic model and a one-stage game-theoretical model.

Future Work

The model can be extended by considering the existence of:

1. Malicious leaders that publish exaggerated values of their parameters to the preselected sets of followers to receive more payments; and
2. Malicious followers that proclaim bogus parameters of their parameters to mislead leaders and push them to pre-select/select them for possible collaboration.

Paper

Omar Abdel Wahab, Jamal Bentahar, Hadi Otrok, Azzam Mourad. “A Stackelberg game for distributed formation of business-driven services communities.” **Expert Systems with Applications** 45 (2016): 359-372.