# Self-sustaining Composed Service Groups for Future Internet (invited paper)

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*Abstract*—**The Future Internet will witness a transformation towards service centric communication systems that will closely support the user's requirements. It is anticipated that these services will not only include web services but also multimedia based services, where each service will be developed to focus on certain core functionalities. In order to maximize user's experience, services will have to be composed into groups in order to integrate various functionalities from different services, and maximize the value to the user. Although a number of research have investigated service composition, a core challenge that still needs to be addressed is the ability to efficiently manage the groups to evolve to meet the changing demand of users as well as new service functionalities. In this paper we propose an adaptive "self-sustaining" mechanism for composed service groups based on bio-inspired techniques. The biological mechanisms used include Lotka-Voltera's competition model as well as chemotaxis based search. Simulation results are also presented in this paper to illustrate the mechanism and functionalities of the bio-inspired techniques selected.**

***Keywords-Autonomic service composition; bio-inspired***

## I. INTRODUCTION

Future communications systems will evolve rapidly, and will lead to challenges of discovering new methodologies to efficiently managing their operations. In particular, a core focus in future communication systems is services that will enhance user's requirements. It is anticipated that there will be large number of services, each with different capabilities and functionalities. Since it is impossible to merge all functionalities into a single service to maximize its value and meet the user's requirements, a good approach is to compose these services together. Composed services could come in the form of merging independent services into groups for supporting specific application (e.g. e-commerce) or can come in the form of adaptation for multimedia streams (e.g. composing filters for video or audio) [3]. Besides supporting user's needs, services will also continually need to merge and update with complementary services that have new functionalities and capabilities.

Due to the large quantity of services available, an efficient mechanism is required to discover and manage these services. Therefore, adaptive and emergent behaviors must be embedded into the services to autonomously manage the service groups, while minimizing human intervention. One form of embodying adaptive behaviour to network services is through applying biologically inspired (bio-inspired) techniques. Applying bio-inspired techniques to different disciplines of science has received wide spread popularity in recent years ([2] [12] [13] [14]). Prehofer and Bettstetter [1] have defined key criterias required for future communications systems, where these criteria include scalability, robustness, adaptability, and efficiency. Based on these criterias, we propose in this paper key bio-inspired techniques that can be applied to composed service groups to exhibit "self-sustaining" capabilities. According to our definition, self-sustaining allows composed service groups to sustain itself throughout the lifetime of the group while meeting the criterias specified by Prehofer and Bettstetter. The self-sustaining capability includes self-managing the group's value as user's demand changes, as well as discovery of new services that enter the market or have updated capabilities. We demonstrate the benefits of using bio-inspired techniques through simulation work.

The paper is organized as follow: In section 2 we provide some related work on service management. Section 3 will breakdown the requirements of future network services, as well as match them to key specific self-governance mechanism. Section 4 will present our bio-inspired autonomous service management solution, while section 5 will present the illustration of the bio-inspired concepts. Lastly, section 6 will be the conclusion.

## II. RELATED WORK

In recent times, a number of research works have investigated different approaches for service composition. Herborn et al [3] developed a distributed mechanism for service composition for multimedia services. The approach investigates mechanism for peer-peer routing between services, service discovery techniques, as well as content description. The objective is to allow disparate services to be combined and separated to various end devices as well as different network interfaces. Miorandi et al [9] developed the autonomic service evolution as part of the EU FP6 BIONETS project. The solution developed incorporated evolutionary algorithm (Genetic Algorithm) that allows services to evolve, depending on the demand of the users. The solution incorporates distributed fitness evaluation, where each service evaluates this individually depending on the demand from the users. Suzuki et al [10] developed a middleware for autonomous agents that are embedded with content services, which were later extended to incorporate evolutionary behaviour [11]. Although, applying evolutionary algorithms provides an optimum solution for service composition, the solutions are based on centralized computation, which will not be ideal for environment of large number of services. Gu and Nahrstedt [15] developed a distributed multimedia service composition systems called SpiderNet that support service composition based on user's requirements while supporting Quality of Service (QoS). The architecture developed by the authors is a three layered architecture, where the functionalities and interdependencies of services are incorporated. Based on these dependencies, service composition is achieved by determining the correct services that correlate to the requirements. However, the solution is largely concentrated on meeting end user's requirements, and not really on system management level.

## III. Requirements and mapping of bio-inspired techniques for Future Network Services

As described earlier, the self-sustaining requirements of composed service groups includes autonomous self-management capabilities as well as discovery of new services.

### A. *Requirements of Future Network services*

The future will witness a large number of services, where these services will not only reside in Application Servers (AS), but may also reside in mobile devices. In order to map the correct bio-inspired techniques to these self-sustaining mechanisms of future network services, we first outline the characteristics based on Prehofer and Bettstetter's criterias for future communication systems.

***Scalability, Efficiency***: Since, there will be a large number of end devices (e.g. AS) that will host services, an efficient search mechanism of right services from large distributed environments is required. In particular, when new services are added to the market, discovery queries will need to efficiently redirect query paths.

***Adaptability***: Services will have very short life span and will continually evolve and change. New and improved services will be deployed into the markets in very short periods. Therefore, groups will need to discover new services that can maximize revenue while improving value for the users. Besides evolving to new services and new functionalities, adaptation is also required to meet changing user's needs.

***Robustness***: Robustness must also be ensured for services that belong to any failed nodes, where new or supporting services can be discovered efficiently to replace services from failed nodes.

### B. *Mapping of bio-inspired techniques*

Based on the requirements defined in the previous sub-section, we have outlined two biological techniques that we have employed and integrated into a single autonomous self-sustaining process for service group management. The two bio-inspired techniques include Chemotaxis, and Lotka-Voltera Symbiosis competition model. We integrate the different biological process as one methodology of meeting the different characteristics required for autonomous systems [2]. A background description of each of the process and their mappings to the autonomous service management will be provided in the next section.

## IV. Self-sustaining composed service group

Our autonomous service management is based on a service overlay network illustrated in Fig. 1. There are three layers which includes the underlying physical layer, service group overlay layer, and service characteristic layer. The organization of services (e.g. serial or parallel) will be individually managed by each service group [3], and is beyond the scope of this paper. Therefore, the diagrams do not reflect the real nature of the composition, but rather just to show how the services all belong to a single group. We assume that there is a specific mechanism in place for description of each services (e.g. [6] [7] [8]), that allows the searching of services that complement the functionalities and requirements of other services. Each service contains a characteristic, defined by $C_{Si}$ for service $S_i$. The relationship between the services is defined through $C_{Si}$.

The following subsections will describe how the bio-inspired mechanisms are used for self-management of composed services, as well as routing based service query.

#### 1) *Service group self-management*

The self-management process of service groups is the ability for the group to maximize and strengthen its value. This basically means the group must be able to cooperatively survive and use the resources from the environment efficiently. The self-management process is performed at the service group overlay layer. The biological process that is used for our mechanism is based on the concept of symbiosis. Our concept is inspired from the works of Kodama et al [4], who used the techniques of Lotka-Volterra competition models [5] for managing TCP congestion (TCP-Symbiosis). The Lotka-Volterra competition model is represented as,

$$\frac{dN_i}{dt} = \varepsilon_i\left(1 - \frac{N_i + \gamma_{ij} N_j}{K_i}\right)N_i \qquad (1)$$

where $N_i$ represents the type of species $i$, $\varepsilon_i$ represents the growth rate, $\gamma_{ij}$ represents the ratio of competition between species $i$ and $j$, while $K_i$ represents the carrying capacity of the environment. The Lotka-Volterra competition model (equation 1) is used to model the competition between multiple species competing for a fixed set of resources.

In our application, the self-management of service groups is analogous to the environment of competing species. Composed service groups must continually evolve to improve sustainability in order to survive and meet continual user's needs and service improvement. This is analogous to species that must survive and evolve by consuming resources in order to maintain survivability in face of any changes from the environment. Based on equation (1), we form the competition models for service groups and is represented as,

$$\frac{dG_i}{dt} = \varepsilon\left(1 - \frac{G_i + \gamma(S_P - S_A)_j}{SP}\right)G_i \qquad (2)$$

where $G_i$ represents the service group $i$, $S_P$ represents total number of services, and $S_A$ represents the services occupied in each group.

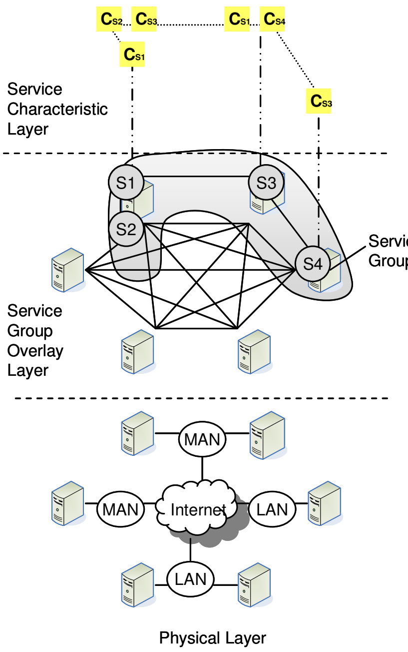


Figure 1. Overlay Application Service for Service Composition

We assume that there exists various ratio of competition $\gamma$ between the service groups, while we have a constant growth rate $\varepsilon$ for each service group. The $\gamma$ is dependent on a number of factors, which includes the (i) the demand from users for the specific service group, and (ii) the amount of revenue ($R_{Gi}$) generated by the service groups.

After integration, equation 2 is represented as,

$$G_i(t) = \frac{G_i(0) f_i(t)(S_P - \gamma_i(S_P - S_A))}{G_i(0)(f_i(t) - 1) + S_P - \gamma_i(S_P - S_A)} \qquad (3)$$

where,

$$f_i(t) = e^{\varepsilon t(1 - \gamma_i(1 - \frac{S_A}{S_P}))}$$

All services initially are stored in a pool - $S_P$, this includes new services as well as services that are released from groups (e.g. services can also be released from groups if they are contributing minimal value to the group). Although services that are released by groups may have little value to the original group, the service will be available at cheaper price and may be compatible to other groups that require its functionalities and only have enough budget ($T_{Cost,Gi}$)for low priced services.

At the same time, groups will be required to maintain the group size in order to maintain group scalability. In order to minimize services being involved with large number of groups (due to limitations at the servers hosting the services), we have a set limit of service groups ($Max_G$). An example of competition for competing services by different groups is illustrated in Fig. 2.

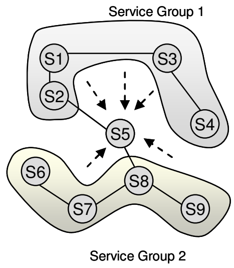


Figure 2. Competition for services

As shown in the diagram, both service group 1 and 2 are keen to enhance their sustainability by discovering and merging with other services. In this particular case, service 5 (S5) from $S_P$ is currently popular and open for joining with any available group. The algorithm for the self-management of service group is illustrated in Fig. 3.

```
for all service groups G_i
if R_Gi < T_RGi or N_Si(t) change
  drop S_i,G from G_i
  begin service query search
  if found S_new
    if C_new,i = C_Gi
       if Cost_Cnew,i < T_Cost,Gi
          add S_new to G_i
```

Figure 3. Self-Management of service groups

### 2) *Routing service based query*

The sustainability process for service group self-management is also dependent on the searching process of new services from the pool. Since our solution ensures efficiency as well as scalability for large number of services, an autonomous distributed search mechanism is crucial. The use of service discovery may be due to, (i) mobility of users within the last hop node who want to access the same services as they migrate to new networks, (ii) addition of new services to the service pool, or (iii) evolving of functionalities to improve service value (this will therefore lead to diverted route discovery). Although the management of service groups is performed at the overlay layer, the discovery process and routing of queries are performed at the underlying network layer.

Our mechanism used for service discovery is through a reactive routing mechanism that is inspired from the biological process of chemotaxis [14]. The chemotaxis process is the process of micro-organism movement to a particular source, where the micro-organism will migrate by attracting to a chemical gradient. We use this analogy to allow queries to drift towards the source, where each source releases the gradient for attracting queries. The chemical gradient released from the source is in the form of hop count value. As the hop count migrates from node to node, the hop count gets deducted. Throughout the lifetime of the service, the service will continually emit out gradient values to maintain its survivability. However, the emission of the gradient value is relative to the demand from users accessing the service. This is represented as, $P_{d,Si}(t) = N_{Si}(t)/N_{ST}(t)$, where $N_{Si}(t)$ is the number of users for the specific service $S_i$, and $N_{ST}(t)$ is the number of total users for the particular class of service $ST$, where $S_i \in ST$. Therefore, as the demand for the particular service reduces, the gradient value will also reduce. The advantage of using the gradient emission technique rather than directed search techniques is that the gradient can automatically change and lead to the most popular and up to date service available in the pool. At the same time, services that evolve and change to improve its functionality will lead to recovery of outdated paths to improve search capabilities. An example of the gradient diffusion process from the perspective of AS is illustrated in Fig. 4. The algorithm for updating the service class values based on the diffusion values is presented in Fig. 5. Fig. 6 illustrates a scenario when a service updated its functionalities, leading to new discovery path.

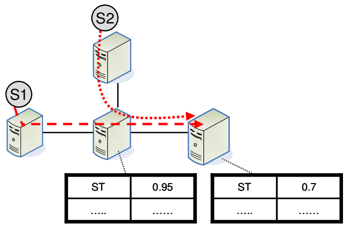


Figure 4. Gradient Diffusion process

```
for all service S_{i,n} (S_i ∈ ST) in node n
if N_Si(t) change
  calculate P_d,Si(t)
  diffuse P_d,Si(t) to node n - 1
  node n - 1 update P_ST
if N_Si(t)<T
  node n-1 remove S_i from table
```

Figure 5. Algorithm for diffusion reinforcement for service class

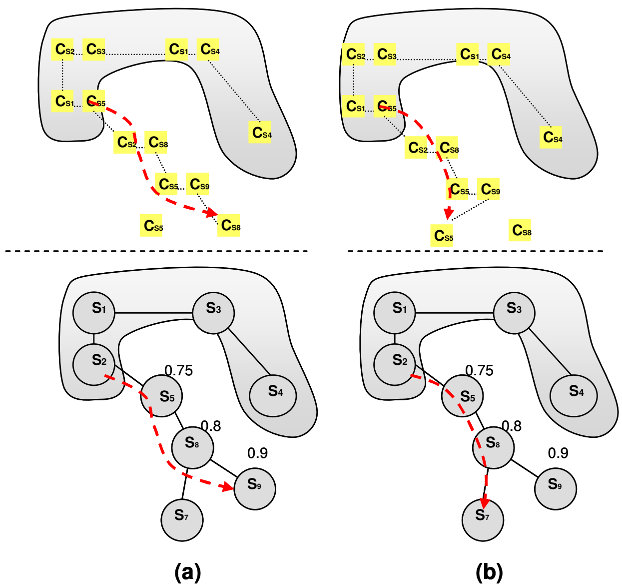


Figure 6. Gradient diffusion process for service query

## V. SIMULATION

In order to illustrate our application of the bio-inspired techniques for composed service group management, we have performed simulations to illustrate their functionalities. In this section we will present two simulation results, which includes the illustration of Lotka-Voltera competition model between service groups for self-management, as well as the routing service based query.

### A. *Service Group Sustainability simulation*

The service group sustainability simulation will illustrate the mechanisms used by service groups to compete for services, and show how services are taken and submitted to the pool throughout their lifetime. The parameters used for the simulation is presented in Table I.

TABLE I. PARAMETERS FOR SIMULATION OF LOTKA-VOLTERA COMPETITION

| Parameters | Value |
|---|---|
| Number of Service Group | 3 ($G_1$, $G_2$, $G_3$) |
| Number of Services | 20, (10 initially in pool) + ($G_1$ - 5, $G_2$ – 3 , $G_3$ - 2) |
| $\gamma_{Gi}$ | $\gamma_{G1}$ – 0.9, $\gamma_{G21}$ – 0.5, $\gamma_{G3}$ – 0.2 |
| $\varepsilon$ | 1.0 |

The results from the simulation are illustrated in Fig. 7. Initially between time 0 - 4, all the groups will try to compete with each other to consume as much services as possible. The most aggressive group is demonstrated from G3, with $\gamma = 0.2$, (where the lower the $\gamma$, the more aggressive the service group will be). This value is reflected from the fact that this service group has higher number of users accessing the service group and in turn is gaining the most amount of revenue. Therefore, due to the high revenue the group is able to aggressively risk and absorb as much services towards its own group. The lowest growth in group size is shown by G1, where $\gamma = 0.9$. At time 3, G1 starts to loose a number of services due to the low revenue generated by the group, and these services are aggressively consumed by G3 and G2. At time 10, a batch of new services is introduced into the pool. Once again the rate of increase in service absorption by each group is proportional to $\gamma$. At approximately time 12, the number of services absorbed by each group stabilizes and at a time 20, a number of services die off due to the low demand and are dropped from each group.

### B. *Routing service based query*

The routing service based query will demonstrate the effectiveness of the chemotaxis based search process. The parameters used for the simulation is presented in Table 2. Fig. 8 illustrates our simulation comparison between the chemotaxis based search and flooding techniques. Our comparison metric is based on the average hop count between the node emitting the query and the AS providing the specific service. As illustrated in Fig. 8, the chemotaxis based search leads to a more scalable and efficient mechanism as the network size grows. This efficiency will not only lead to shorter query routes, but will also minimize the number of query messages transmitted which may be very large when the number of services as well as groups grow.

TABLE II. PARAMETERS FOR CHEMOTAXIS QUERY SEARCH

| Parameters | Values |
|---|---|
| Average Connectivity | 2 edges/node |
| Average Hop count between AS | 5 – 20 (Uniform Distribution) |
| Average number of services per AS | 1 – 20 (Uniform Distribution) |

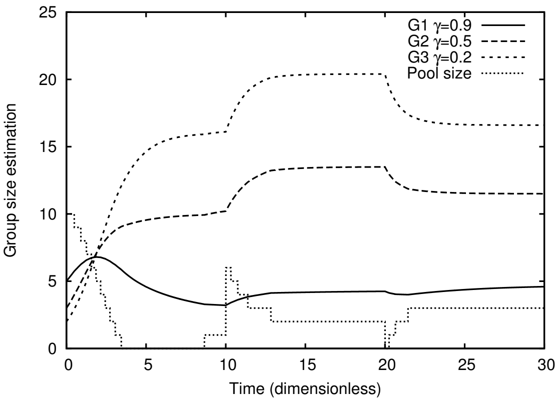


Figure 7. Simulation of Lotka-Voltera competition model

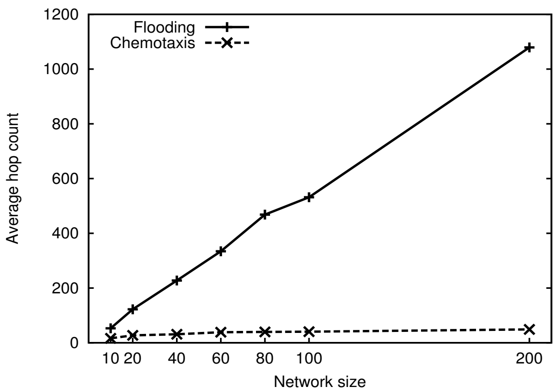


Figure 8. Simulation of flooding vs. chemotaxis service query based routing

## VI. CONCLUSION

The future internet will be largely centered around supporting user's requirements and applications, which is largely driven by services. In order to support this requirement, a large number of services will need to be developed. While services will be embedded with functionalities, it is impossible to have all functionalities embedded into a single service that meets all user's requirements. Therefore, a core requirement is the ability to autonomously compose these services into groups. In this paper, we propose the use of bio-inspired techniques to autonomously self-sustain composed service groups. In particular we have applied the Lotka-Volterra's competition model for self-management as well as chemotaxis based service discovery. Simulation results have also been presented to illustrate the techniques that have been applied.


## ACKNOWLEDGMENT

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