Media-Oriented Service Composition with Service Overlay Networks: Challenges, Approaches and Future Trends

(Invited Paper)

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Abstract— **The massive and timely delivery of media is gradually integrating itself with the dynamic composition of media-oriented services so that new types of customized media services can be created according to the diverse demand of end users. The resulting effective and differentiated networking support will become one of the most important requirements of the network infrastructure in the future. In this survey paper, we first present the emerging trend on the interaction of media-oriented service composition and overlay-based networks by introducing related technical issues. Then, we describe the top-down and the bottom-up approaches that coordinate service mapping using the service overlay networks (SONs) and provisioning resources for them, respectively. Finally, we examine latest research on futuristic overlay networks for service realization.**

Keywords: Service oriented architecture, media-oriented service composition, service mapping and placement, service overlay networks, and P2P networks.

I. INTRODUCTION

In the last decade, quite a few new network architectures, including the overlay network, the content delivery network (CDN), and the peer-to-peer (P2P) distributed network, have emerged to facilitate the massive and timely distribution of continuous media, *e.g.*, audio and video. Continuous media delivery has gradually integrated itself with the dynamic composition of media-oriented services to result in new customized media services so as to meet the diverse demand of end users [1], [2]. Effective and differentiated network support will become one of the most important requirements for the future network infrastructure. In this survey, we attempt to review the emerging trends on the interaction of media-oriented service composition and overlay/P2P networking.

In Fig. 1, we depict the evolution of service composition methodologies from the viewpoint of dynamically coordinating the service and resource (*e.g.*, processor, memory, bandwidth, storage) components. Fig. 1(a) shows the traditional methodology where each of service components is tightly integrated and consequently composed for the monolithic service. This methodology, which has dominated in the Internet, is no longer suitable because it cannot accommodate increasingly diversified requirements of end users. In addition, since the services randomly share a common resource infrastructure for data delivery, it is difficult to provide a certain level of quality of service (QoS).

Fig. 1(b) presents the concept of service composition, where the service overlay network (SON) is employed as an intermediate layer to facilitate the flexible creation of services and the resource provision for QoS. Composing basic service components in such a manner allows more flexibility and reusability in building media-oriented services. However, balancing the quality among multiple instances of composed services remains unresolved because either allocated resources are confined to the network bandwidth or they are logically partitioned.

Fig. 1(c) depicts an ideal and futuristic methodology for service composition, where virtualization techniques will evolve to fully partitioned resources without interference. This allows the dedication of proper set and amount of resources to each service component to flexibly provision resources for the composed services. If we can develop a scalable and reliable coordination mechanism (with or without an additional layer) between the composed service and virtualized resource components, it offers an ideal solution for the future. However, this kind of research is still in the beginning stage.

In line with the evolution of service composition methodologies, we examine the network support for

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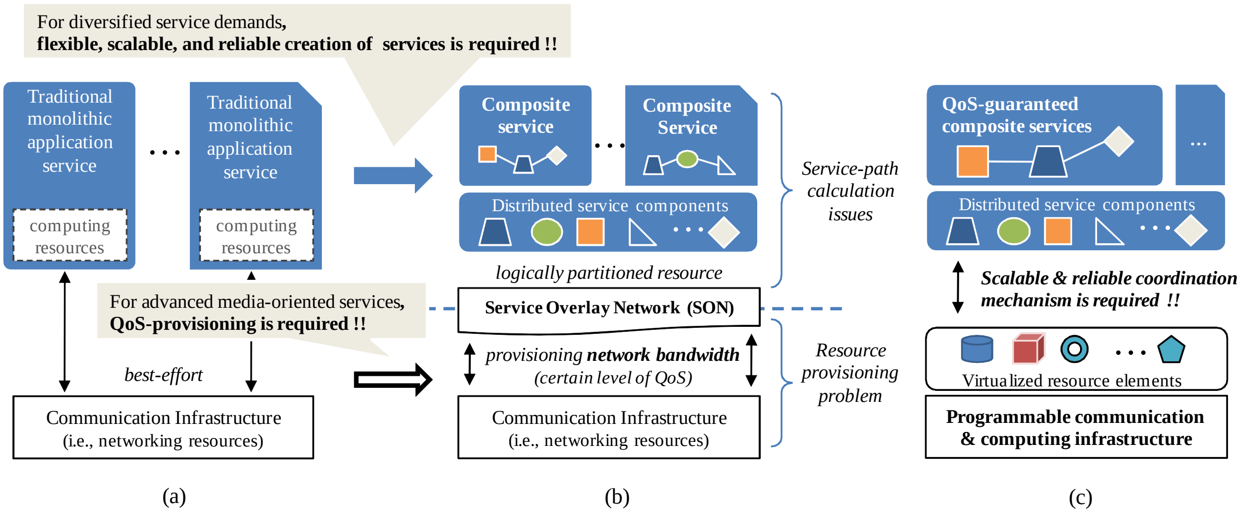

Figure 1. Evolution of service composition methodologies: (a) the traditional, (b) the current and (c) the future one.

media-oriented service composition with the following coverage:

- Understanding media-oriented service composition and its support via SONs;
- Coordinating service mapping/placement on top of SONs (top-down approaches);
- Preparing SONs for the QoS of composed services (bottom-up approaches);
- New types of overlay networks for futuristic service composition.

In this paper, we provide a survey on the interaction[1] of media-oriented service composition and the overlay/P2P network infrastructure. Due to its wide scope, relatively little effort has been made to explain the above interaction. By focusing on the SONs, we attempt to provide a balanced survey that overviews related issues and the evolution of approaches from both top-down and bottom-up directions. It is worthwhile to point out that there exist overview papers on each of the two topics individually. For example, we refer to [3] for more in-depth discussion on service composition and [1], [4] for its media extension. We also refer to [5], [6] and [7] for structured/unstructured P2P overlay networks, general classification about overlay networks and multimedia distribution over overlay/P2P networks, respectively.

The rest of this paper is organized as follows. In Sec. II, we present the emerging trend on the interaction of media-oriented service composition and overlay-based networks by introducing related technical issues. Then, focusing on the SONs, we describe the top-down and the bottom-up approaches about the interaction in Secs. III and IV, respectively. Afterwards, we present the latest research on futuristic overlay networks for service composition in Sec. V. Finally, concluding remarks are given in Sec. VI.

II. OVERVIEW ON MEDIA-ORIENTED SERVICE COMPOSITION AND SERVICE OVERLAY NETWORKS

A. *Media-Oriented Service Composition*

Over the last decade, there has been a huge increase of media contents delivered through the Internet. As the personal need about multimedia services grows, flexibility-driven multimedia systems have become critical to support diversified media contents and tools, compose new contents, and deliver contents across various computing and networking environments. To realize this vision, research and development under the general name of the service-oriented architecture (SOA) [3], [8] has been conducted to address the fundamental issues of service composition. In the SOA paradigm, complex tasks are first decomposed into smaller independent entities that support interoperability (*e.g.*, web services, which are the most popular implementation of SOA). Then, flexible service composition can be performed in a variety of ways.

This paradigm has made a broad impact to the multimedia community. That is, we see a migration from monolithic multimedia applications to flexible component-based ones. This concept also helps build large-scale multimedia applications by composing diverse media-oriented services on demand. However, due to the resource-savvy characteristics (in terms of bandwidth and delay/delay jitter) of multimedia applications, a direct application of web-based research results is still difficult. Many characteristics of web service composition and media-oriented service composition were comprehensively compared in [4].

Combining the web-based service-oriented concept and the sophisticated handling and processing of multimedia data brings the benefit that enables the reuse of existing services and provides an attractive way for dynamic production and customized delivery of media contents to end users. It is expected that the emerging complex tasks in the multimedia domain will demand a strong

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[1] Most interaction approaches surveyed in this paper are generic for any kind of service composition while they are applicable to the case of media-oriented service composition with special arrangements.

support of service composition so as to build systems in a scalable, easy-programmable and flexible manner. Generally speaking, media service composition is a process where multiple media services (*e.g.,* media retrieval, transcoding, display services) are connected via functional and data dependencies to create a new composite service (*e.g.,* a video-on-demand service) over heterogeneous and distributed network infrastructures. A taxonomy of media-oriented service composition was given in [1], which provides a classification of service composition to support complex media workflows and presents methods for media-oriented service composition in detail.

We use an example as shown in Fig. 2 to explain the concept of media-oriented service composition [9], [10]. It provides a service composition scenario for distributed video editing and streaming in a futuristic personalized broadcasting system, which supports user-friendly interface via haptic-interaction, 3D visual display and surrounding sounds, and customized video editing and composition. In this system, both live content streaming and on-demand content services feed multimedia data continuously, and the video composition service mixes these two streams into an integrated and customized stream according to the demand of end users. The caching service provides speedy duplication of media data with local storage. The multicast service enables multi-destination delivery of the stream. In this example, two display services are shown to illustrate heterogenous display environments with different capabilities in processing power, screen resolution and network bandwidth. The networked display service can receive multiple tiled streams via the multicast service directly and present the contents on ultra-high-definition displays. On the other hand, the normal display service, which cannot receive and process all streams due to lack of computing/networking resources, relies on the transcoding service for stream conversion.

To realize the above service composition in a systematic way, several modeling schemes have been proposed. They are classified into categories of static composition (services to be composed decided at design time), dynamic composition (services to be composed decided at run time), automatic composition (no user intervention) and manual composition (user-driven composition). Dynamic and automatic composition can be further categorized into the following three types [2], [11].

- Artificial intelligent (AI) scheme
  Examples include the finite state machine and Petri Nets. This scheme is often used to model the relationship between components of a complex service. Although the ideas of various AI methodologies look promising, they are difficult to apply in practice.
- Semantic scheme
  Examples include rule-based and service dependency graph methods. This scheme examines service compatibility, takes both functional and non-functional requirements into account, and allows reasoning on which component is best to use in each situation.
- The middleware scheme
  Examples include policy-based, input/output dependency methods. This scheme enables functionalities and access to resources available from different organizations. It allows applications to be adaptable, reconfigurable and fault-tolerant.

The middleware scheme is more feasible among the above three since it enables seamless and reliable service composition with careful observation of resource availability.

By taking the media-oriented service composition in Fig. 2 as an example, we can represent the targeted service composition, called a composite service, as an aggregation of component services with a functional service dependency graph [9]. Under given pre-/post-conditions[2], the service dependency graph indicates the process of serving a purpose in the SOA.

Each component service is specified by the following elements: 1) service name (representing the primary functions of the service); 2) service code (implementing the atomic work item of the service and permissible to be replaced by a software tool or a workflow for an atomic task); 3) pre-conditions and post-conditions (being matched in a transition from one service to another service); and 4) execution time (indicating a period in which the service should be run). The performance of each component service is characterized by

- computing cost – CPU usage rate and memory/storage volume consumed in data processing;
- networking cost – delay and bandwidth needed for data transmission;
- availability – the probability to execute the service successfully;

and other QoS performance metrics. Then, by binding and consuming resources in running the aggregate of component services, a composite service would fulfill desired QoS performance requirements (*e.g.,* execution time, pre-/post-conditions, etc.) of the composite service.

Several metrics have been proposed in [12], [13] to evaluate a composite service. They include:

- execution time – equal to the sum of the execution time of each component service involved in this composition (in the case of sequence composition) or less than the sum (in the case of parallel composition);
- computing cost – the amount of computing resources of all component services;
- networking cost – the amount of networking resources of all component services;
- composition sustainability – presenting the possibility of available alternative compositions when one or more component services fail.

B. Challenges in Network Support

To enable the media-oriented service composition, the system-wide support should be arranged. It usually begins with modeling a target composite service through appropriate component services. Then, to fulfill the composition requirements, we have to discover, select, negotiate

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[2] The pre-condition and post-condition are synonymous for respective input and output QoS parameters (*e.g.,* media formats).

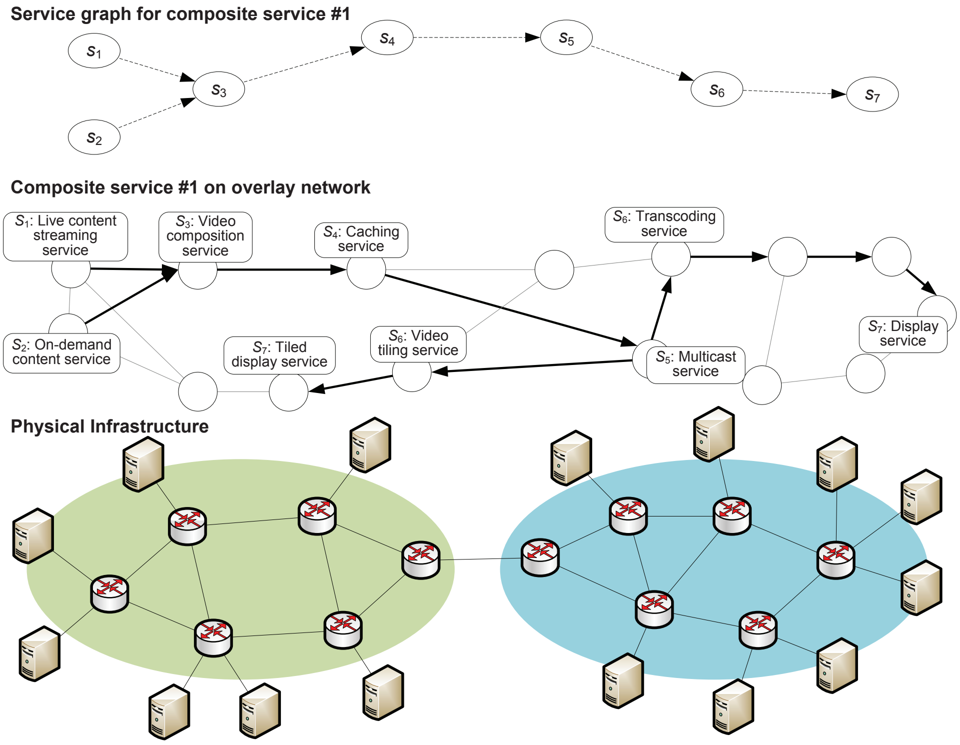

Figure 2. The conceptual diagram of media-oriented service composition.

and execute services. For service discovery, we need a repository to store the information of all available services and process queries about services. Typically, several nodes in a network can act as repositories and, depending on the number of nodes involved, the repository itself can be either centralized or distributed. Other essential operations (*e.g.*, name resolution, proxy operation, etc.) can be deployed on dedicated and possibly distributed nodes in the network. Due to the diverse nature of the supporting networks and devices in terms of availability, bandwidth and quality, it is challenging to create a transparent platform to execute the desired media-oriented service composition.

We may state the above challenges more formally. In order to create a large-scale distributed media application, the underlying infrastructure (systems and networks) must provide a strong support across multiple protocol and service layers for the overall service composition process. Challenges to enable large-scale multimedia systems and applications are listed for infrastructure and semantic data aspects, respectively, in [4]. They are summarized below.

- Challenges in the network infrastructure – *QoS mechanisms for service composition* and *QoS-aware policies for service composition*.
- Challenges in the system infrastructure – broad availability of multimedia OS, *automated service graph establishment* and handling heterogeneous devices.
- Challenges in semantic data modeling for composition – modeling of service synthesis, service discovery, service selection and service execution.
- Challenges in creating semantic meta-data for compositions – media-oriented service taxonomies and semantic ontology multimedia language.

The items highlighted in italic font are specifically related to the network support for media-oriented service composition. These challenges are demanded by QoS-provisioning for media-oriented distributed applications/services. They cover the whole fused process of service composition via service modeling, mapping coordination, and resource provisioning/management.

Furthermore, interactive coordination and management should be arranged among key players such as end users, network providers, and service providers. The issue of "who will play the leading role in this interactive coordination/management" is important, since each choice may impose a distinctive set of requirements. It is related to the efficiency of the whole solution, leading to the scalability of a large-scale deployment.

C. From Overlay Networks to SONs

An overlay network can be simply viewed as a network that is built on top of another network [6]. Nodes in the overlay network can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network. With this general definition, P2P networks are overlay networks when they run on top of the Internet. In [5], which contains an extensive survey and comparison of various structured and unstructured P2P networks, P2P networks are viewed as one type of overlay networks. The P2P overlay networks offer a long list of features, including selection of nearby peers, redundant storage, efficient search/location of data items, data permanence or guarantees, hierarchical naming, trust and authentication, and anonymity. P2P overlay networks potentially offer an efficient routing architecture that is self-organizing, massively scalable, and robust in a wide area, combining fault tolerance, load balancing and explicit notion of locality. They are known to provide a good substrate for large-scale data sharing, content distribution and application-level multicast applications.

The merits of P2P overlay networks have spurred numerous trials in a wide range of applications and services with an objective to utilize fully-distributed, cooperative network power with peers to build a self-organizing system. All previous experience has led to a formal definition. That is, an overlay network is an application-layer virtual or logical network in which end points are addressable and that provides connectivity, routing, and messaging between end points. It consists of peer nodes that self-organize into a distributed data structure based on the application criteria. The resulting overlay networks provide the flexible and extensible functionalities to emerging services via an underlying network that is inflexible and cannot adapt to the dynamically varying requirements.

In early years, most overlay networks were designed as an alternative solution to support value-added services such as multicast [14], fault tolerance [15], security [16] and so on (Also refer to separate discussion about Active Networks in Box #1). They also attracted a lot of attention from the industry as a means to deliver QoS-sensitive services over the Internet. Meanwhile, most of them were end-user overlay networks constructed among end hosts without support from intermediate nodes in the underlying network (*e.g.*, routers). The initial overlay networks did not leverage the information of the underlying network topology and, as a result, experienced significant performance problems such as high link stress and increased end-to-end latency due to topological inefficiency.

To facilitate existing and futuristic QoS-aware applications, a new framework to support overlay applications is demanded [18], [19], [20]. Instead of application-specific overlays, proposals have been made to develop a general overlay network, called the SON, which is to be shared by a variety of applications. In this context, overlay networks are proposed as a service backbone for QoS support. This is needed since supporting the end-to-end QoS of media-oriented services is difficult with pure end-user overlay networks. An integrated overlay is envisioned where each overlay network is managed by a third party.

Besides the capability to provide the end-to-end QoS for media-oriented services, the SON architecture has several important advantages. For example, it decouples application services from network services, thereby reducing the complexity of service QoS management and control in the network level. The underlying network domain is simply concerned with provisioning of data transport services with associated bandwidth management, traffic engineering and QoS guarantees on a much coarser granularity (per SON). Note that the SON introduces a new level of traffic aggregation called service aggregate, and the underlying network aggregates traffic based on the SONs they belong to and performs traffic and QoS control accordingly based on the corresponding service level agreements (SLAs). For example, a service-oriented P2P system, called the P2P service overlay, was proposed in [21], where peers provide media files as well as a number of application service components such as media transcoding, data filtering and application-level data routing.

D. Design Issues in SONs

In this survey, we advocate the SON as an effective means to provide media-oriented service composition with QoS guarantee. There have been studies on SONs and their architectures that consist of different types of overlay networks targeting at different functionalities. Examples include end-user SONs, backbone SONs and underlay abstraction for SONs. They are detailed below.

1) End-user SONs: End-user SONs seek to provide application-aware functionality by pushing the complexity to end users. Currently, several end-user overlay networks such as MBone (multicast backbone) [22], CAN (content addressable network) [5], and RON (resilient overlay network) [15] have been designed and deployed to support value-added services. They deal with issues such as constraint-based topology generation, QoS-aware routing, fault recovery/resilience networking and load balancing.

One example of the end-user SON is the P2P-based SON in [21]. Another example is the RON proposed in [15]. The RON routes packets through paths optimized for application-specific metrics. RON nodes actively monitor the quality of paths connected to their neighbors and decide where to route packets based on collected information and application requirements. Similarly, the spine overlay architecture [23], [24] uses the hop-by-hop reliability of overlay links to reduce latency and jitter of connections. By applying TCP-like loss recovery and congestion control on each overlay link, this approach can detect packet loss faster and recover packets locally.

Although being highly flexible by decoupling services from the network, end-user SONs usually cannot guarantee end-to-end QoS, since this overlay architecture has to cross many intermediate domains, where some domain may not provide the desired QoS support to end users. Moreover, it is difficult to develop an attractive business model for ISPs (Internet Service Providers) to adopt end-user overlays.

2) Backbone SONs: In backbone SONs, networks managed by a network service provider are used as a service backbone to support end-to-end QoS [18], [19], [20], [25]. A backbone SON was proposed in [18], where the network bandwidth has certain QoS guarantees from individual network domains to build a logical end-to-end service delivery. It simplifies the network QoS management, makes it more scalable and enables flexible creation

BOX #1: Active Networks: Active networks [17] refer to a variation to the traditional network architecture in which the network switches perform customized computations on messages flowing through them. It is developed to assist user applications that perform user-driven computation at nodes within the network. To realize active networks, two schemes have been experimented. In the discrete scheme, the message processing task is architecturally separated from the business of injecting programs into the node, with a separate mechanism for each function. This preserves the current distinction between in-band data transfer and out-of-band management channels. In the integrated scheme, every message is a program. Every message or capsule passed between nodes contains a program fragment (or at least one instruction) which may include embedded data. When a capsule arrives at an active node, its contents are evaluated and processed. However, active networks were not widely deployed due to issues in security, resource allocation, and the deployment cost.

and deployment of new (value-added) services. Similarly, QRON (QoS-aware routing in overlay networks) [20] used overlay brokers and a general unified framework for an overlay network. Another proposal called QUEST (QoS assured composEable Service InfrasTructure) [19] went furthermore by composing qualified service paths with multiple QoS constraints and load balancing from the SLAs of individual service components. OverQoS [25] presents a controlled loss virtual link (CLVL) abstraction to provide Internet QoS (*e.g.,* statistical bandwidth and loss rate assurance) using overlay networks and to perform bundled loss control on each virtual link.

These backbone SON researches usually focus on one aspect of service provisioning. For example, bandwidth dimensioning was studied in [18] while overlay path composition was examined in [19]. Some studies were dedicated to the introduction of an overlay architecture to enhance Internet QoS. For example, the hierarchical QoS routing architecture that balances the overlay traffic was proposed in [20], and the overlay-based QoS architecture that provides bundle loss control and resource management within a bundle was discussed in [25]. However, little work has been done to address the integrated performance of backbone SONs.

3) Underlay Abstraction for SONs: The concept of backbone SONs can be further elaborated via SONs supported by the underlay (*i.e.,* the underlying layer) [26]. The functionality provided by the underlay abstraction can be used by several overlay services at the same time to remove redundancy so that network resources can be used more efficiently. To give an example, the SON provides and maintains direct transport links between nodes, encrypts overlay (control) traffic, protects integrity, and provides generic transport mechanisms to deal with underlay characteristics (*e.g.,* physical network topology, mobile terminal handover, and multi-homing). More importantly, the underlay abstraction allows us to use native underlay mechanisms (such as QoS support and native IP-multicast support) transparently. In other words, the underlay abstraction can absorb the complexity of supporting heterogeneous network protocols (*e.g.,* integration of IPv4 and IPv6, support of new mobile connectivity) and isolate it from applications. All these functionalities can be accessed by overlay services and applications using a generic interface.

On top of underlay abstraction, self-organizing overlay networks was considered in the SpoVNet [26]. A similar idea was also proposed in the autonomic network architecture (ANA) [27] and others. As part of Ambient Networks, SATO [28] enables flexible creation of service-aware transport overlays on top of the network layer using the Ambient Networks node identity (NID) layer. We will discuss SONs based on this underlay abstraction in Sec. V-A.

III. TOP-DOWN APPROACHES VIA SERVICE MAPPING COORDINATION

Researchers have started to address the challenges of effective network support for media-oriented service composition since early 2000. Some studies have taken top-down approaches from the viewpoint of end users who create customized services for themselves. They usually assume the availability of SONs that connect service overlay nodes in the application level, sometimes separating them from the underlying networks. These efforts are summarized in this section.

A. Coordination for Service Mapping

A SON consists of distributed overlay nodes connected by application-level links, which are called (virtual) overlay links. The resulting SON topology can be formed by connecting an overlay node with a number of other nodes called neighbors. Application-level data relaying is required between two overlay nodes that are not directly connected. Then, by utilizing the computing/storage resources of itself, each overlay node can host one or more media-oriented service components (*i.e.,* component services). When the placement of media-oriented services is not given (*i.e.,* services are only prepared in a central service repository waiting to be launched), an application has to request, map and upload component services into the physical overlay nodes of the SON infrastructure to complete the service dependency graphs.

For given SONs, the *service mapping* problem can be defined as follows. By representing a media-oriented service composition request with a service path that connects service components, it is concerned with the mechanism that maps this service path onto overlay service nodes in the SON while meeting the QoS requirement. Under such a context, the *service placement* problem is to determine which node in a SON to perform a target service [29]. Sometimes, the targeted service model and SON are pre-determined so that the service coordination problem is reduced to the service mapping problem. The quality-aware service composition (QSC) problem in the SpiderNet [10] is an example.

One way to classify SONs is based on the service dependency graph used in service composition modeling. Depending on the number of media sources and end users (called the destination) of the graph, we may have the following combinations: the single-source single-destination (SSSD) case, the multiple-source single-destination (MSSD) case, and the multiple-source multiple-destination (MSMD) case [30]. Also, whether the composition order among component services is fixed or dynamic provides another angle to examine service composition.

In this section, we categorize the service mapping coordination into the following three cases, which also reflect the common order of algorithm development from centralized toward distributed.

- Centralized coordination;
- Decentralized (including distributed) coordination;
- Hierarchical coordination for scalability.

B. Centralized Coordination for Service Mapping

Service mapping coordination in a centralized manner is the most straightforward and has been heavily examined from the early stage. By determining the best service mapping based on the collected overall status, this coordination can be realized effectively. The weak points are that it loses the flexibility of matching the need of each end user and it may encounter the scalability challenge due to centralized coordination loads. Specifically, for a SON constructed and managed by a service provider, which is a common scenario for the time being, it is natural to adopt this centralized coordination. The following example of QUEST explains how the centralized coordination is made in detail.

In a centrally managed SON such as QUEST [19], portals define the management boundary of QoS provisioning for composed applications. Each node represents a service component, which is managed by an individual component service provider (CSP). Each CSP can control quality levels of its own services based on the SLA with the portal service provider (PSP) while the PSP has an SLA with the user for each composed service. To allow the PSP to monitor and manage quality levels of the composed service, a centralized authority (called the SON portals) that serves as the entrance/exit points of the SON is introduced. In QUEST, each service instance (or service link) is offered to the PSP via the SLA that specifies its QoS provisioning such as availability (A), response time (RT) or delay (D).

For each user request, the QUEST service composition model includes two mapping steps:

1) mapping the request to a composite service template
   This mapping is constrained by the application-specific quality requirements of end users and pervasive client devices such as PDAs and cell-phones.
2) mapping the template to a service path
   This mapping is constrained by the distributed performance (*e.g.,* response time) and the resource availability conditions.

C. Decentralized Coordination for Service Mapping

The distributed nature of media-oriented service composition and the rapid deployment of distributed P2P overlay networks have demanded a change in service mapping coordination. When customized SONs are created by collaborative distributed overlay nodes, service mapping has to be decentralized as well. Several prototype systems [21], [30], [31], [32] have been proposed along this line.

In the SPY-Net [31], overlay nodes called SPYs are deployed at different locations to form an application-level SON, where a relatively small number of SPYs (*e.g.,* less than one hundred SPYs) was used. The service mapping demands dynamic changes of resources such as the SPY capacity and connection bandwidth between SPYs. The SPY-Net utilizes a monitoring mechanism to propagate the availability information of resources of the underlying network. That is, each SPY monitors its own capacity and the connection bandwidth from itself to a selected subset of other SPYs. These results are periodically propagated to other SPYs so that each SPY can maintain a global view of the SPY-Net called the SPY-Net monitoring graph (SNMG). Based on the SNMG, each SPY executes the decentralized service mapping for each service path request submitted to it locally.

Being built upon P2P SONs, the SpiderNet [21] extends the SPY-Net by fully distributing service composition so as to provide statistical multi-constrained QoS assurance and load balancing for composed services. Each overlay node is associated with a statistical resource (*e.g.,* CPU, memory, disk storage) availability vector. Then, the QoS-aware service composition is formulated to determine the best mapping for a desired service composition. The SpiderNet adopts bounded composition probing to provide scalable quality-aware and resource-efficient service composition in a fully distributed fashion. Specifically, the probe for a service composition request, which carries the information of a target service DAG (Directed Acyclic Graph)[3] and the QoS/resource requirements of users, is processed independently at each peer using the local information only. The resulting decentralized coordination finds the best qualified service flow that satisfies the multi-constrained QoS requirements and achieves the best load balancing on top of underlying SONs.

The QoS service routing problem was investigated in [30] for both the one-to-one and the one-to-many (or multicast) scenarios. Although component services are distributed among multiple hosts, the system can still provide integrated services seamlessly and efficiently. By distributing its service and resource information with a link state protocol, each host can maintain a global view of all nodes and links in the system. With this information,

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[3] In a service DAG, any path that goes from the source to the sink node satisfies the service functionality and dependency requirements.

the best qualified service path can be computed with a conventional graph algorithm (*e.g.*, the Dijkstra algorithm) over the service DAG. For the one-to-many scenario, a special multicast service can be used to save the network bandwidth and host resources by employing an efficient QoS-assured service tree (rather than multiple individual service paths).

Pietzuch *et al.* [32] proposed a stream-based overlay network (SBON), which locates suitable nodes to place stream operators. The SBON was designed using a multi-dimensional metric called the cost space, which contains the routing cost between two nodes in terms of some measurements such as latency and processing power. Every node in the SBON maintains its cost space. The SBON determines the placement of a query in the virtual cost space with a relaxation algorithm and then maps its decision back to the physical node space.

D. Hierarchical Coordination for Service Mapping

Due to the growing demands in pervasive computing applications, it is important to support user tasks in a dynamic environment, where we face challenges of heterogeneity, resource restrictions, scalability and mobility. To address the scalability problem, we may coordinate the generic service composition in a hierarchical manner [2], [33], which can also be extended for the case of media-oriented service composition. Some examples are given below.

An interesting example that applies this hierarchical approach is the DSMR (Distributed Service Matrix Routing) algorithm [33]. For scalability, a hierarchically organized network is envisioned with groups of nodes combined into ASs (Autonomous Systems). Each AS has a service controller and a set of service nodes. Usually, each AS is small enough for the controller to have a complete view of its topology. For larger ASs, one can extend this design by allowing more than one service controller within an AS. The routing protocol can be divided into two different levels:

- Intra-AS routing
  It determines the path within an AS, where a centralized layered graph algorithm is used.
- Inter-AS routing
  It determines routes between ASs, where a distributed algorithm (DSMR or approximate DSMR) is used.

SeSCo [2] employs a four-level classification to achieve transparent hierarchical support. Generally speaking, the computing resources with relatively lower resource restrictions are mapped into a higher level to support essential operations such as service discovery, service composition, and proxy operation for their resource-poor counterparts.

- Level 3
  Resources such as servers and clusters are classified to level 3, the highest end of the spectrum.
- Level 2
  User devices with mobility such as laptops and PDAs are classified to level 2.
- Level 1
  Resources that host the middleware and accommodate native support for delegates to execute but cannot act as proxies for other resource-poor devices are classified to level 1.
- Level 0
  Level-0 devices are those to which a proxy is assigned to make its features available as services.

Hierarchically organized resources are used to build a SON, which is facilitated by a latching process. The basic principle is that a device of lower resource availability latches itself to another device of higher resource availability, which is repeated until the highest level 3 is reached. With the resulting hierarchy, SeSCo coordinates service composition by weaving a complex service with basic services dynamically. Each device informs all available services to its parent at the time of registration. It also maintains a service zone that includes all services available through it and all its children. Given a service composition request, each device searches required services from its service zone (and later its parent's service zone) and then compose the requested service to meet the need using the aggregated service I/O parameter graph.

IV. BOTTOM-UP APPROACHES VIA OVERLAY NETWORK PROVISIONING FOR SERVICES

In contrast with the top-down approaches, other studies have been conducted from the bottom-up viewpoint. That is, based on the availability of resource substrates (*e.g.*, CPU, memory, storage, and network), these approaches construct quality-controllable SONs to support media-oriented service composition.

The SON architecture relies on well-defined business relationships between SONs, the underlying network domains and users. To support the end-to-end QoS, each SON obtains network resources with certain QoS guarantees from individual network domains via the SLA (*e.g.*, for a usage-based or fixed price service policy) to build a logical end-to-end service delivery infrastructure on top of existing data transport networks. One common drawback of these SONs is that they suffer from weak scalability in an inter-domain environment. In practice, each service instance of SONs will involve multiple underlying management domains in service composition. Among many provisioning-related challenges, we are concerned with the following bottom-up approaches from the viewpoint of the resource side:

- Network resource (*e.g.*, bandwidth) provisioning;
- Computing resource (*e.g.*, server) placement;
- Managing efficient overlay network topology;
- Managing effective reliable and redundant routing.

A. Resource Provisioning for SON

To end users, two kinds of resources are critical for the success of service composition; namely, computing and networking resources. Thus, we can classify resource provisioning for scalable and manageable SONs into the following two cases:

- network QoS
  Examples include bandwidth provisioning and delay management. Monitoring the condition of overlay links allows SONs to get the state information of the underlying networks and dynamically react to performance degradation by sending its traffic via routes that still fulfill QoS requirements.
- resources in overlay nodes
  This is especially important for server nodes that process and manage service flows. In SONs, each service flow is routed by sending the data to overlay servers. The location of different overlay servers is essential to the functioning of SONs, and good server placement algorithms will greatly enhance the SON performance.

1) Network QoS: The SON bandwidth provisioning problem was mathematically formulated in [18], where several critical issues (*e.g.*, cost recovery in deploying and operating the value-added services) were analyzed. The framework accounts for factors such as SLA, service QoS, traffic demand distributions and bandwidth costs. Moreover, analytical models and approximate solutions were developed for both static and dynamic bandwidth provisioning.

The capacity allocation problem in an economic framework was addressed in [34], where a novel routing scheme was incorporated in a traffic-revenue optimization framework to approximate the state-dependent routing scheme in SONs. Then, a capacity allocation scheme was derived employing the notion of the link shadow price in the routing layer, which reflects the sensitivity of net revenue to the dimensions of the links.

2) Overlay Nodes: Several network planning issues such as the choice of overlay node location and budget costs were considered in [35]. Besides, SONs were optimized by relaxing conventional assumptions, *e.g.*, the full coverage of all traffic demands, no bounds on overlay links capacities, and pre-determined number and location of overlay nodes. Two novel optimization solutions were proposed to address the joint user assignment and traffic routing problem, which determines the optimal assignment of users to access overlay nodes and the capacity reservation for each overlay link while taking traffic routing into account.

As to the server placement problem, Shi and Turner [36] formulated a set covering problem that determines server locations by minimizing the distance of every client to its nearest overlay server. While servers were placed strategically at peering points of the network to interconnect as many ISPs as possible and serve more service requests, there was no deliberation on the effect of server placement on network topology.

Vleeschauwer *et al.* [37] extended the server placement problem by considering the overall QoS degradation in the core network. They proposed algorithms to place overlay servers in best-effort networks so that their connections have end-to-end paths to fulfill bandwidth and delay requirements. They focused on the design of a SON that maximizes the number of unicast and multicast connections with deterministic delay requirements, yet without considering link costs.

The overlay node placement problem was also investigated in [38] to improve routing reliability and TCP performance. They attempted to enhance the application performance through topology-aware tactical node placement. While this tactical construction improves the efficiency and performance of overlay networks, it is actually focused on maintaining good connectivity among overlay nodes and minimizing message delay in the network.

B. Operational Management for SON

Strict resource constraints are imposed on the service paths to meet the QoS requirements of applications and enhance the network performance. Furthermore, operational management is required to maintain overlay networks effectively for service composition. In this subsection, we discuss operational management for service overlay paths in two aspects: 1) dynamic topology management and 2) QoS routing and route restoration.

1) Dynamic Topology Management: In a connection-routed overlay network, localizing QoS degradation to a single domain is of great importance since different domains may be managed by different network providers. Identifying the domain allows the service provider to attribute the degradation to a single network provider. A distributed monitoring scheme was proposed by Jiang *et al.* [39] to address this issue. However, their solution was not practical since a source node was assumed to have the complete information of all intermediate nodes along the established connections. This is not valid in inter-domain connections. Furthermore, additional traffic is generated to facilitate the monitoring process, which consumes resources.

Vieira and Liebeherr [40] formulated the SON topology design problem as a cost optimization problem. Two subproblems were considered separately: 1) the assignment of an end-system to an overlay node and 2) the selection of transport links between overlay nodes to relay traffic between end-systems. A simulated annealing method was used to provide solutions to large-sized networks, where routing was not optimized and traffic flows were routed by considering the cost as well as the shortest path. Moreover, the overlay topology design problem was addressed in a simplified network scenario, where the number and location of overlay nodes are pre-determined.

The dynamic topology construction problem was also considered by Han, Waston and Jahonian [41] with an objective to adapt to the underlying network topology changes. An architecture of topology-aware overlay networks was proposed in [41] to enhance the availability and performance of end-to-end applications by exploring the dependency between overlay paths. Several clustering-based heuristics for overlay node placement and a routing mechanism were introduced.

Dynamic overlay network reconfiguration was studied in [42] to determine the optimal reconfiguration policies that accommodate time-varying communication requirements and minimize the total overlay network cost. Another set of heuristics for SON design was presented in [43] with an objective to construct an overlay topology that maintains the connectivity between overlay nodes in face of various IP-layer path failure scenarios.

2) QoS Routing and Route Restoration: QoS routing refers to a set of routing algorithms developed to identify a path that has sufficient network resources to satisfy the QoS requirements of an overlay connection. Most QoS routing algorithms also consider the optimization of resource utilization. To facilitate QoS routing, the state of every link in the network should be expressed in terms of a set of QoS metrics such as delay, bandwidth, jitter and cost [44]. The metrics of links along a path are aggregated to form the QoS metrics of a path. A connection can express its QoS requirements in form of constraints on QoS metrics of one or more paths [45]. These constraints are compared with the desired QoS metrics of paths through the network so that the one that satisfies the constraints can be selected. Shi and Turner [46] presented a heuristic scheme to the multicast application in SONs by selecting routing algorithms that optimize the delay and the bandwidth usage of multicast service nodes.

When QoS degradation is expected or detected, the service provider should restore the connection via an alternate path. Most research efforts have focused on proactive schemes [47], where resources are reserved along a primary path with one or more secondary (or backup) paths [48]. To support proactive schemes, the QoS routing technique should support multi-path routing [49]. The backup paths may extend end-to-end between the source and destination nodes [50] and may be totally or maximally disjoint with respect to the primary path.

A connection can be restored with minimal delay using proactive schemes. However, it wastes resources due to duplicate reservations. Also, it may not guarantee restoration since simultaneous failures could occur along primary and secondary paths. To address this problem, reactive restoration that rapidly determines and restores the connection via an alternate feasible path after the occurrence of a failure/degradation is also desired. Reactive schemes could be applied end-to-end or between two neighbor nodes of the failure node. However, end-to-end restoration incurs a long delay that increases with the distance between the source and destination nodes. The impact of the failure is also distributed along the failed or alternate path. As a result, the end-to-end restoration is probably not the best alternative in restoring an inter-domain connection.

C. Next Generation SON and Others

Future service environments are expected to consist of mixed operators such as providers/users (*i.e.,* prosumer), content-centric heterogeneous devices, and programmable service infrastructure. There is still no unified and generic SON architecture as the service backbone, where the network is service-aware while the service is network-sensitive, to achieve dynamic context-aware service composition. More efforts in the SON upgrade are needed to support generic QoS provisioning in the future.

With the foreseen evolution, it is important to organize services offered by various SONs and provide access to stake-holders such as end users and providers. One attempt to build such an infrastructure is known as NGSON (next generation SON) [51], which helps providers organize and improve their business by offering rich services to their end users so that they can support the growing lifestyle of end users. Along this line, NGSON targets a new SON to bridge the service layer and the transport layer over the IP infrastructure to address the accommodation of highly adaptive, flexible, and integrated services. NGSON will standardize the IP-based SON architecture for the life-cycle management of multiple, value-added collaborative, information and communication services, independent of underlying transport networks. Although the entire framework is still in an initial stage [51], some entities such as the collaborative service plane, the network plane, the operation and management plane, and others are being discussed. It also specifies context-aware, dynamically adaptive, and self-organizing networking capabilities including advanced service-level routing and forwarding schemes.

Also, as reviewed in Sec. IV-A and Sec. IV-B, most research on finding a service path in SONs has addressed problems in wide-area service composition such as fault-resilience, adaptability and resource contention. QoS consistency and load partitioning in composing a service path for ubiquitous computing environments have also been studied in several SON projects. Besides these issues, P2P-oriented traffic localization to potentially improve the quality of SON is investigated by the IETF ALTO (Application Layer Traffic Optimization) effort, which standardizes a protocol to enable P2P applications to obtain information regarding network layer topology [52]. For example, the P4P (proactive provider assistance for P2P) [53] offers a promising service delivery framework candidate for ALTO that enables ISPs and application services to work cooperatively to optimize application communications.

V. DIRECTIONS FOR FUTURISTIC SON DESIGN

In this section, we present latest research on futuristic SON design. We expect that media-oriented services will become increasingly interlinked with the physical environments of individuals, communities and business entities in the future. New ways of service creation and consumption will emerge, aiming to cover different application needs and preserve revenue generation of various stakeholders. It is difficult to realize such a vision with today's Internet due to its architectural limitations. Paving the way for the future service network demands a more drastic change. For example, it may involve fundamental architectural changes together with specific improvements of individual technologies (*e.g.,* more bandwidth, more content and more services), which may not be enough to meet the goal on their own. Also, better alignment between technical capability and business need is critical. There are three promising directions: 1) SON upgrade using multiple virtualized overlays; 2) adoption of an eco-system approach; 3) network service abstraction, as detailed below.

A. Multiple Virtualized Overlays

Although NGSON in Sec. IV-C is currently designing a practical approach for next-generation SON, a lot of major improvements are still required in order to support generic and flexible resource provisioning for futuristic SONs. We discuss several developing ideas that accommodate the promising virtualization technology as below.

The concept of service-aware adaptive transport overlay (SATO) [28] proposed by the Ambient Networks project adopts a generalized overlay system structure. SATO aims to provide a flexible and customizable transport services to the application layer using overlay network instances, which are set-up and torn down on demand on top of any type of transport- or network-layer connectivity. It introduces a uniform overlay infrastructure to support multiple applications and provide them with useful functionalities realized inside the network paths, thus providing an abstraction of the underlying network (*i.e.,* functional blocks for the composition of new overlay services). The individual overlay instances enable a flexible configuration of virtual networks consisting of SATO overlay nodes. The overlay network topologies respond to the application requirements and enable point-to-point, point-to-multipoint and multipoint-to-multipoint services.

Similarly, the SpoVNet (Spontaneous Virtual Networks) [26], [54] allows spontaneous creation of a common communication context (*i.e.,* self-organizing SON) based on application-specific requirements. With the underlay abstraction, it provides generic functionality to cope with mobility, multi-homing, and heterogeneity. The underlay abstraction actually comprises two components. First, the base communication provides connection-less and connection-oriented communication between endpoints identified by sets of network locators. Second, the base overlay provides node identifiers for addressing, implementing an ID/Locator split.

Being different from the existing pure P2P overlay, the SpoVNet is aware of the underlying network infrastructure (*i.e.,* underlay-awareness) in several aspects. First, with a generic interface to underlay functionalities, it allows transparent deployment of native underlay mechanisms for mobility, multi-homing, and others. Second, it utilizes the so-called cross-layer information service (CLIO) to provide the measurement information for the optimization of application-specific overlays. Third, it helps applications request connectivity with specific requirements (*e.g.,* security, latency, QoS) in an abstract way, free from network-specific concerns. Last, it uses optional SpoVNet booster nodes in the infrastructure to increase efficiency and performance of communications. With all these arrangements, the SpoVNet targets at flexible, adaptive, and spontaneous provisioning of application-/network-oriented services on top of heterogenous networks with the hope that some selected services can be part of the futuristic network infrastructure.

Recently, Davie *et al.* [55] introduced a service provider-hosted overlay, which can be interpreted as a transient mechanism to build futuristic SON smoothly. The proposed service provider-hosted overlay allows the same node entity to link both the underlay and the overlay. By leveraging the underlay, an overlay network provides an appropriate means for experimenting with new functionality in the network. The service provider-hosted overlay implements a set of functions in the so-called “service routing layer”. Service providers can assist those applications, which benefit from added functions such as caching and streaming support, without interfering with other applications that do not need the added functions.

The European research group on FCN (Future Content Networks) claims that the future Internet will be content-centric and new developments include: simplifying usability, increasing efficiency, and enhancing users’ service experience (*e.g.*, flexible communications, immersion, interaction) [56]. Since the current Internet cannot efficiently serve the increasing needs and foreseen requirements, the FCN group proposes two content-centric Internet architecture: 1) a ‘logical content-centric architecture’, which consists of different virtual hierarchies of nodes with different functionality, and 2) an ‘automatic content-centric Internet architecture’, which is an object-based approach relying on content-aware functionality. Based on the available information and service delivery requirements and constraints, these architectures can be easily scaled to multiple levels of hierarchy in overlays, clouds, virtual groups of node, or content objects. Note that important trends on content-based networking [57] are related to these research efforts.

B. Service Overlay Ecosystem

From the service management viewpoint, the service provisioning infrastructure can be seen as a dependability hierarchy, where today’s network service is not placed at the bottom of a hierarchy as traditional layering suggests. Following this approach, one concludes that service management must not only estimate fairness, robustness, versatility and cost efficiency of the network service features but also drive them with appropriate resources. It is worthwhile to point out that today’s feature-rich IP-layer functionality calls for an optimized network- and service-layer solution to foster richer connectivity aiming at a network version of SOA. To achieve the *network SOA*, SONs are only an intermediate step since overlays are usually underlay-agnostic and they over-stretch underlay resources.

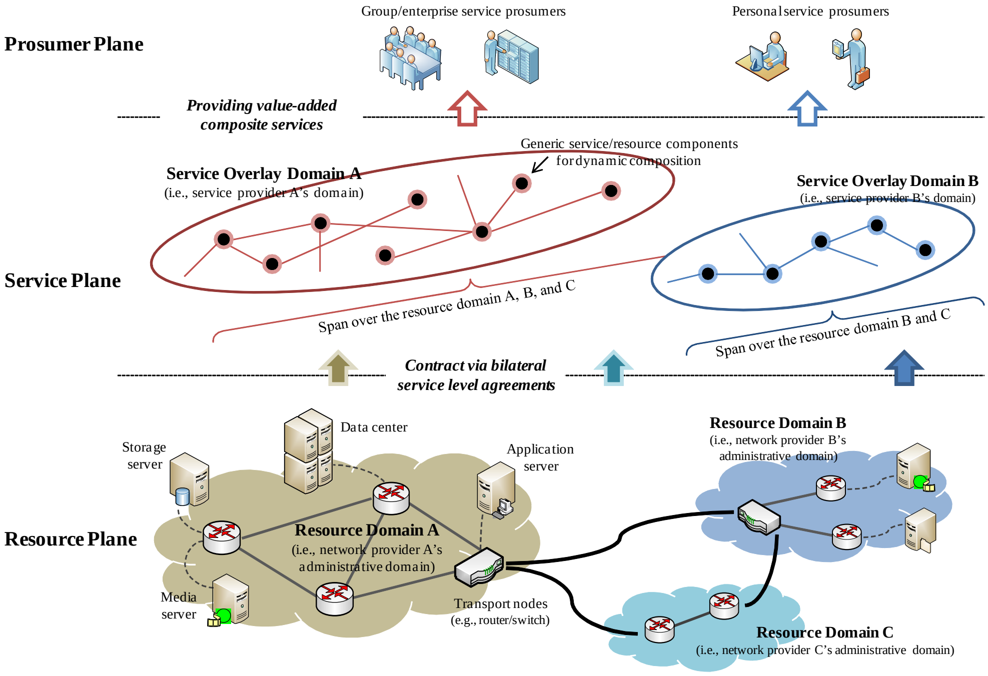

Figure 3. The service overlay ecosystem.

A new paradigm called the *service overlay ecosystem* [58], [59] is shown in Fig. 3. It has many features common with those of an ecosystem. It can help keep the design and maintenance complexity under control while meeting the requirements of end users and service/network providers at the same time. Generally speaking, an ecosystem is defined as a system of interactions between living organisms and their environment. The ecosystem concept has an important advantage. That is, it considers the underlay and potentially numerous overlays as a single ecosystem, where different overlays may compete for resources. However, resource utilization is close to optimal in both underlays and overlays, and allocation of underlay resources is fair.

In the design of a service overlay ecosystem, SLA networking and automation is an important issue. Pongpaibool and Kim [58] extended the SLA offering across ISP boundaries, which is currently limited to a single provider. Three policies were introduced to coordinate the end-to-end performance guarantee in multiple ISP networks; namely, the least effort, the most effort, and the equal-distribution policies. Meanwhile, a set of models was considered in [59] to automate the translation (decomposition) of domain-specific SLAs into lower-level resource requirements, typically, thresholds of resources needed to meet SLA's objectives.

A resource-provisioning SON, the AptusNet, proposed in [60] considers distributed service components and virtualized computing and networking resources for service composition. To handle various contexts of media-oriented services, each component in the AptusNet is offered well-controlled QoS beforehand for specific services. To resolve the complexity in composing heterogeneous service components, it decomposes the role of service-providing agencies into the following three entities:

- the service overlayer
  It is responsible for QoS-aware composite services over multiple underlying domains. It negotiates with service and resource aggregators to discover proper candidates and manage the selected components.
- the service aggregators
  They holds the information about the service components distributed in their domain.
- the resource aggregators
  They store the abstracted information about the virtualized resources of the programmable substrate in their repository.

Although the AptusNet only provides higher-level abstraction without considering a particular platform or algorithms in the service composition and resource provisioning process, it attempts to take a holistic view of futuristic service design by allowing users to compose services with the virtualized resources dynamically so as to meet end users' requirements.

C. Networking Service Abstractions

Among the clean-slate approaches of the future Internet, several efforts define new and open network service abstractions based on the SOA principles (Also note the separate discussion about Cloud computing in Box #2) [61], [62], [63]. They provide building blocks of fine-grained functionality and accomplish highly-configurable complex communication tasks by combining elementary blocks.

BOX #2: Cloud computing is a style of computing in which dynamically scalable and often virtualized resources are provided as a service over the Internet [64]. Users need not have knowledge of, expertise in, or control over the technology infrastructure in the "cloud" that supports them. Cloud computing embraces cyber-infrastructure, and builds upon decades of research in virtualization, distributed computing, grid computing, utility computing and, more recently, networking, web and software services. It implies SOA, reduced information technology overhead for the end user, greater flexibility, reduced total cost of ownership, on-demand services and many other things. Service-orientation is another driving force to enable cloud computing to further realize reusability, composite applications, and mashup services. SOA hides the complexities of middleware, database and tools. In addition to offering middleware or development tools as services in the cloud computing environment, some common utilities such as on-boarding, provisioning, monitoring, billing tools, or cross-industry services. The concept generally incorporates combinations of the infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS).

The role-based architecture (RBA) [61] was the earliest work in developing a network service abstraction for service composition. RBA organizes communications by composing functional blocks called roles. RBA achieves this by providing explicit signaling of functionality. The metadata in a packet is divided into chunks called role-specific headers (RSHs). An RSH contains a list of role addresses to which this RSH is directed and a body containing role data items. Any node along the path can add an RSH to a passing packet. RBA provides a model for packet header processing, not a mechanism for routing packets. It can incorporate any forwarding mechanism so that a practical RBA would retain the IP layer of the Internet with its high-speed forwarding machinery and efficient packet header.

SILO (Service Integration, controL and Optimization) [62] suggests a new network service abstraction that employs a similar service composition approach advocated by RBA. It gives more focus on facilitating "cross-layer" interactions to meet the exact user requirements and optimize performance. The SILO architecture provides a control entity that is able to tune the parameters of individual blocks to match the application QoS requirements and improve network resource utilization.

Being different from RBA and SILO, Ganapathy *et al.* [63] considered a new scheme, where network services are accessed explicitly by end-systems for novel end-to-end communication paradigms. The network services encompass functions that have been traditionally placed on end-systems and functions that are typically placed on routers. They utilize a representative control entity to determine the placement and configuration of services along the network path. With a service socket abstraction, end-system applications can specify data path services in connection requests.

VI. CONCLUSION

In this survey, we discussed the gradually-increasing demand on the fused interaction of media-oriented service composition and overlay-based network support. We first clarified the meaning and challenges regarding media-oriented service composition. We also introduced the SON as the key enabler for efficient and flexible service composition. By reviewing the existing work about the interaction of media-oriented service composition with the underlying overlay/P2P network infrastructure, we identified several different yet inter-related approaches and presented their key concepts and examples.

More specifically, the evolution on ideas about service mapping coordination is surveyed to illustrate how the media-oriented service composition could be realized by matching the topological nature of employed SONs. The review about SON resource provisioning explains the complexity of securing sufficient resources to overcome the operational variations while maintaining the overall efficiency. We then introduce how the overlay-based network support is currently being generalized in order to design new extensions for future SONs. We however are limited in clearly differentiating the interaction case of media-oriented service composition from that of generic service composition, especially for the bottom-up approaches.

Finally, we would like to emphasize that the media-oriented service composition for the future Internet is still an active on-going research topic. Newly created services based on the futuristic network infrastructure are rapidly emerging nowadays. We hope this survey can provide a quick and extensive glimpse of existing ideas as well as several new concepts for futuristic SONs.

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