SIONA: A Service and Information Oriented Network Architecture

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***Abstract*—The Internet is a great hit in human history. However, it has evolved greatly from its original incarnation. Content distribution is playing a central role in today's Internet, which makes it difficult for the conventional host-to-host communication to meet the ever-increasing demands. In this paper, we present a novel "service and information oriented network architecture" (SIONA). The key aspect of SIONA is the name-based two-dimensional routing paradigm that provides scalable routing, caching and content delivery. We argue that SIONA solves the problems of mobile Internet by naturally supporting mobility, and provides multi-source multicast and network layer P2P for massive data distribution. Evaluation is conducted to investigate its caching and mobility performance.**

I. Introduction

Current Internet adopts a point-to-point communication model that emphasizes the end-to-end paths or channels. Packets carrying addresses simply flow in the channel. This model has achieved tremendous success, with millions of people surfing the Internet everyday. However, demands have tremendously changed since IP was born. It is accepted wisdom that contents play a central role in today's Internet. The end-to-end principle has significant limitations when dealing with massive content delivery. The dual role of IP addresses to signify both the location and the identity is seen as the source of the ills. Many believe that the traditional address-based network is evolving to an information centric network (ICN). To adapt to this tideway, architecture innovation is required to support highly scalable and efficient content distribution.

The information centric network has produced plenty of results in the international Future Internet research activities. Triad [1] proposes to explicitly include a content layer in the routing architecture to provide content routing, caching and content transformation. DONA [2] builds on Triad's name-based routing, but uses flat, self-certifying names. ROFL [3] proposes that the network layer not contain location information in the packet header, but to route directly on the flat labels. NDN (originally called CCN) [4] proposes an entirely new architecture, which builds a 'universal overlay' for content centric network. Jacobson et al [5] evaluate the performance of NDN by implementing a Voice over IP (VoIP) application.

In this paper, we present the initial results of a service and information oriented network architecture (SIONA) aiming at following goals:

- Efficiency: Millions of clients are requesting billions of contents on a daily basis. New contents are emerging in a exploding manner. The design should support content transmissions effectively.
- Scalability: It is believed that the number of world-wide data pieces is approximately on the order of 10^{16} [6]. To cope with these mass contents, the system should be extremely scalable .
- Mobility: Mankind has entered the age of mobile Internet. The existing Internet protocols are not well-suited for mobile services. The architecture should provide users with ubiquitous mobility support.
- Logos innovation: The increasing desire for accessing information, independent of who published it and where it is located, requires innovation of communication paradigm. New architectures should address the requirement of evolving from current address-centric network to an information-centric network.

The key feature of SIONA is the service and information oriented paradigm. We define Information as static data, for example, a video file, and define Service as the activities that are to meet customers' demands, e.g., streaming services via YouTube. Service as well as information are identified and routed by names. Providers register services to the network. Receivers achieve contents by issuing request packets (containing the names of the service and information). Data is pulled from possible sources by the requests, which travels a reverse path to reach the end nodes. Along the path, intermediate forwarding nodes may cache the data to meet potential future requests.

SIONA exploits a name-based two-dimensional routing. We leverage service names to perform inter-domain routing and use information names to route packets within the same domain. DNS is involved to map service to a specific domain. The use of existing DNS keeps SIONA from introducing extra mapping system and provides fine scalability (discussed in section VII). SIONA differs from ID/LOC split schemes in the way that SIONA moves from the original communication model of a flow of bytes from a source to a destination to a "clean-slate" architecture that is based on a content-driven paradigm triggered by end-user requests.

The design of explicitly distinguishing service and information is driven by the following motivations:

- Efficient and effective data delivery: It's common that multiple copies of a content item are available in the network. The information centric paradigms alone inherently cannot support services because of the emphasis on retrieving content. Manipulating services independently avoids redundant consumption of service node resources

(e.g. CPU cycles, memory, energy) [7].

- Service migration: The emergence of cloud computing and virtualization technology makes it trivial that the location of services dynamically changes. Extracting services from contents will benefit routing discovery when service migration happens.
- Scalable content routing: Maintaining 10^{16} content indexes in routing tables cannot handle the necessary scales. Separating service from information enables the system to dramatically reduce the routing table in a Map & Encap manner [8], as is demonstrated by existing ID/Loc split schemes [9, 10].

SIONA provides innovative solutions to massive data distribution by implementing mechanisms of multi-source multicast and network layer P2P. We argue that SIONA not only provides scalable content distribution, but also solves the problems of mobile Internet by naturally supporting mobility. We are developing a prototype router (BitEngine 12000) and are designing SIONA with support from National Basic Research Program of China (973).

The rest of this paper is organized as follows. Section II presents SIONA's overall architecture. Section III shows how this design inherently supports mobility. Section IV describes SIONA's ability on multi-source multicast and section V presents how SIONA supports network layer P2P. Section VI presents the design of a coordinate caching algorithm. Section VII analyzes the scalability issues. Section VIII evaluates the proposed caching scheme as well as SIONA's mobility performance. Finally, we conclude our work in section IX.

II. Architecture

A. Naming Scheme

SIONA is designed to be a service and information oriented platform that meets the requirements listed earlier - efficient, scalable, allow publishers and subscribers to be unaware of each other's identity, and support ubiquitous mobility. SIONA adopts a name-based paradigm, which provides identification, routing, caching and transformation for service and information.

SIONA names consist of data names and attributes. Data names are of the form of S (Service) : I (Information). S is service name that specifies a particular service, e.g., YouTube. I is information name that indicates the desired data, e.g, the file of Harry Potter (Figure 1).

Neither S nor I is designed to be human readable. S is the hash value of the service name. I is the hash value of the whole content (the hash of the information name as well as the information itself). Some well-suited algorithms, such as MD5 and SHA-1, can be leveraged to calculate the hash function. In such a way, the combination of S and I uniquely defines a content (although there is opportunity that collision may happen, it is really rare in practice).

The attributes contain three parts: O (Offset), L (Length) and F (Flag). O indicates the distance from the beginning of the data to the current data block, which is in term of byte. L is the length of the data block. The existence of O and L makes it possible for SIONA routers to realize multi-source multicast and network layer P2P (as we will show in section IV and section V). F is a flag bit which indicates whether the name has been performed a DNS lookup. If yes, F is set to be 1, otherwise it is set to be 0 (explained further in section II-E).

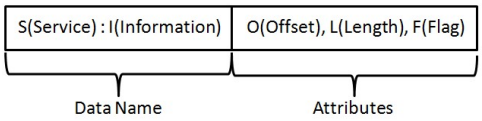


Fig. 1. SIONA name structure

B. SIONA Packets

Three types of packets are defined: register packet, request packet and data packet. While these packets perform different functions, they have two fields in common:

- Name: Identifier of service and information, including data name and attributes
- Options: Field that carries additional information, such as priority, preference, etc.

Register packets are used by servers to register information (not service) to the network. Register packets can be forwarded among SIONA routers to propagate registration information. They can only be propagated within a single domain. OSPF-like intra-domain routing protocol(s) can be invited to perform the registration propagation.

Request packets are sent by end users to pull services and information from the SIONA network. One request packet can be decomposed into several sub-requests using the Length (L) and Offset (O) fields, and forwarded to SIONA network to get service and information from multiple sources in parallel (explained further in section IV and section V).

Data packets are the reply of request packets, which carry the required data. A time-to-live (TTL) field is used in data packets to decide how long they will be cached in SIONA routers (explained further in section VI).

C. Service and Information Registration

Routing and forwarding in SIONA is based on four tables which are maintained by SIONA routers: Registration Table (RT), Request Interface Table (RIT), Data Store (DS) and Forwarding Information Base (FIB). RT is used to keep the information registration within a single domain. RIT is used to remember interfaces of requests which have been forwarded but are still waiting for matching Data. SIONA routers provide caching functionality and DS is used to keep cached data. FIB is used to forward packets based on the existing IP network.

To populate service, a service provider registers the service to DNS. We define a new DNS record type *RI* to keep the service registration information. The key of the *RI* record is the name of the service and the corresponding value of the *RI* record is the domain of the service provider (server). DNS publishes the service to the network as it does to today's domain names, which makes the service globally visible. For security considerations, DNSSec [11] can be used to provide authentication of service names.

To populate information, servers send register packets to SIONA routers. The registration packet carries the name of the information. Routers build entries for the information in their RTs and disseminate information among other routers within the same domain. Note that the registration information won't be inter-domain populated. OSPF-like intra-domain routing protocol(s) can be invited to perform the intra-domain registration propagation. Technical details of such protocols are beyond the scope of this paper.

D. Constructing Reverse Paths

Upon receiving request packets, routers store the requests in their RITs, where each entry contains the name of one request as well as the request's coming interface. Different interfaces with the same request name are stored in the same entry. When data packet arrives, the router checks which entry matches the data's name and forwards the data to all the interfaces that are waiting for the data. In this way, data gracefully travels a reverse path to reach the destination. A multicast delivery can be inherently implemented in this way, which will be explained in detail in section IV.

RIT entries are contained by 'I', which means 'S' is not included in a RIT entry. Each RIT entry is assigned with a Time to Live (TTL) value, which indicates how long the entry can be kept. Longer TTLs can be assigned to entries of popular information. An entry is removed from the RIT if either of the following events happens:

- Data arrives and is disseminated to all the interfaces listed in the entry.
- The TTL of the entry expires.

Figure2 shows the construction a reverse path. We emphasize that the idea of RIT borrows from NDN.

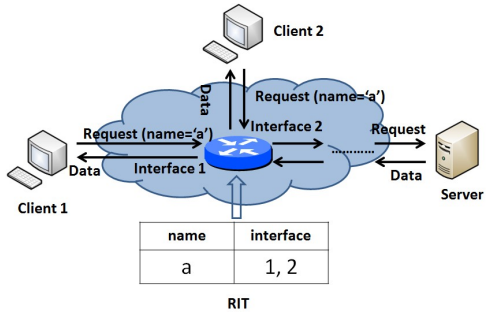


Fig. 2. Constructing a reverse path

E. Routing and Forwarding

To receive service and information, end nodes send out request packets, which carry service and information names. The first router which receives the request packet queries DNS for the residing domain of the service. If a valid domain is returned by DNS, two cases will happen exclusively.

- Case 1, the router and the service reside in the same domain. In this case the router directly forwards the request to the server by looking up its registration table (RT). If the information has been registered, an entry for the information will exist and the request is forwarded according to the entry. Otherwise the packet is dropped.
- Case 2, the router and the service reside in different domains. In this case the router tunnels the packet to the domain which contains the service. In such scenarios, FIB is used to forward the encapsulated packet. Once a router in the service's domain receives the request, it decapsulates the packet and the process then degrades to case 1. The router forwards the packet to the specific source according to its RT. Existing protocols such as MPLS, or new schemes can be used to perform the tunneling. Details of particular tunneling technologies is beyond the scope of this paper.

In case 2, the router caches the service's domain for a certain period of time. Following requests for the same service can be directly routed without querying DNS. Note that only the first router along the path queries DNS. After achieving the domain of the service, the router sets the F field in the name structure to be 1, which keeps other routers from querying DNS again.

Although global services form an immense namespace, it is accepted wisdom that only a slight number of services are accessed by majority of users. By carefully designing replacement policies, we believe that routers can get rid of wearing out by DNS queries.

If a router fails in getting the service's domain, the packet will be dropped. In order to reduce the computing and communication cost, routers won't feedback error messages when packets are dropped. Timers should be implemented at end nodes to detect such failures.

Having routers perform the service resolution instead of endpoints relieves applications from service management, which achieves the same effect as many ID/Loc split schemes advocate, such as LISP [9]. The FIB table of SIONA routers can be constructed using existing technologies of today's IP network, such as OSPF and BGP. The scalability issue of this approach is discussed in section VII.

Whenever receiving a request, SIONA routers remember the interface from which the request comes by adding an entry in their RITs.

Once the request reaches a node which has the data, data packets will be sent back. The node that meets the request can be either a server, or an intermediate router which caches the information. Data packets trace the reverse path created by the request packet back to the end node. When data packets arrive, SIONA routers forward the packets to all the interfaces which match the data's name by checking their RITs and then remove the corresponding entries.

Along the path, SIONA routers cache the data in their DSes. In such a way, following requests which carry the same name will likely pull the data from a nearby cache, which minimizes the delay and bandwidth consumption. Figure 3 shows the above logic, in which client C1 - C4 request the same content in a sequential manner.

III. Inherent Support for Mobility

Existing Internet is not designed to deal with mobility because of the location-based addressing scheme of IP where

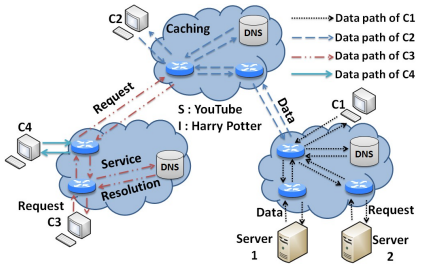


Fig. 3. SIONA data transmission paradigm

IPs are tied to geographical areas [12]. There are two basic approaches for maintaining reachability: routing and indirection [13].

As the routing-based approach suffers from slow convergence and routing state explosion, indirection methods, such as Mobile-IP [14], are considered to be practical in reality (as Mobile-IPv6 has not been widely used, we refer to Mobile-IPv4 in this paper). However, all Mobile-IP based solutions have the common problem of triangular routing, which leads to longer delay and wasting of network resources. In SIONA, mobility is inherently supported. We show how SIONA supports client mobility and server mobility respectively.

First, if a client moves, the client achieves seamless handover by keeping on issuing request packets. A new reverse path is automatically established by SIONA routers, which guarantees data packets to reach the client. In contrast, Mobile-IP needs to first perform the handover registration and then encapsulate the packet using a triangular route. In some cases such as traveling on high-speed trains (up to 300 km/h), Mobile-IP may lead to bad user experience due to registration bursts (500-1000 cell phones handoff at almost the same time). SIONA does not have this problem as no handover signaling is required. Figure 4 illustrates the scenario, in which BSes represent base stations.

Second, if a server moves, one of the following cases will happen exclusively.

- The server moves within the same domain. In this case, no special operation is required to preserve the communication. The server just keeps on issuing registration packets to provide information. Request packets from the client will be routed to the server's domain as it was and SIONA's intra-domain routing scheme guarantees the request to reach the server.
- The server moves to a different domain. In this case, the server updates DNS with its new location. Dynamic DNS [15] can be used to quickly notify the change. When the cached location for the service in routers expires, intermediate nodes can achieve the server's new domain from DNS and recover the communication. To achieve seamless handover, a rendezvous point can be optionally set to temporally redirect requests to the moving server.

With the flourish of cloud computing and virtualization technology, it has become trivial that service migration often occurs. SIONA naturally supports mobile content services, which makes it well-suited for today's innovation trend.

IV. Multi-Source Multicast

It has long been ill to deploy inter-domain multicast protocols in IP networks. The major impediment for such protocols is the cost of establishing multicast states. In SIONA, it is straightforward to solve this problem as the RIT table already maintains the states.

It is natural for SIONA to support multicast with a single source. The server sends data packets only once, and the data cached in DS is leveraged to provide multicast distribution. A group of destination nodes can simultaneously receive data in a single transmission from SIONA routers that create copies automatically. This is the one-to-many communication.

In an content centric world, there will typically be multiple sources which serve the same information. SIONA proposes a many-to-many communication paradigm that a group of clients can request the same data from multiple servers in parallel. Request packets can be disseminated by SIONA routers, so that service and information can be achieved from multiple sources simultaneously. Length (L) and Offset (O) fields can be used to maintain the state in these scenarios.

V. Network Layer P2P

As time goes on, different routers may keep different parts of a single information. SIONA routers can explicitly notify other routers about its cached information within the same domain. One router can request information from its nearby nodes in parallel.

In such a way, we can provide SIONA with an innovative functionality: Network Layer P2P. One request can be split up into arbitrary pieces using O and L, and be forwarded to arbitrary SIONA routers to retrieve the desired information in parallel. Note that the request split is done by SIONA routers rather than the applications. For instance, when a SIONA router receives a video request, it splits the request into three slides with the first slide representing the period from the beginning to 40min, the second slide representing the period from 41min to 80min and the last slide representing 81min to the end. It then forwards the slides to three SIONA routers which have the corresponding movie period and receives the video content in parallel. This provides a scalable and efficient solution to content distribution for the data-explosion world (figure 5).

Note that there is a subtle difference between network layer P2P and multi-source multicast. Multi-source multicast refers to the idea that a group of receivers can fetch data from a single transmission, while network layer P2P enables information to be decomposed and disseminated through the network at router level and one SIONA router can get the information from multiple routers in a distributed manner.

VI. Coordinate Caching Policy

As stated above, data can be cached along the path to meet potential future requests. SIONA exploits a TTL based coordinate caching policy to take advantage of the widespread principle of locality. The basic idea is that the closer routers reside to receivers, the longer they keep the data. Each piece

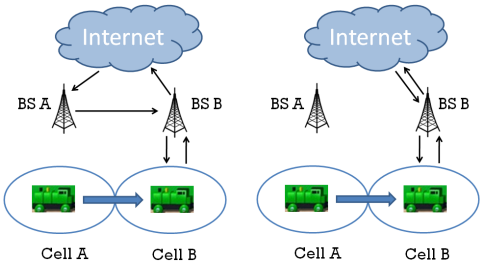


Fig. 4. Handover of Mobile-IP and SIONA

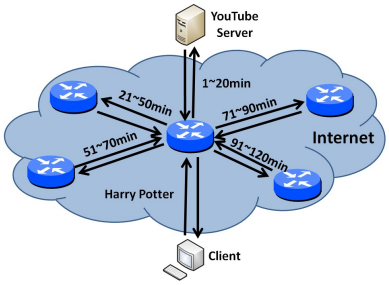


Fig. 5. Network layer P2P

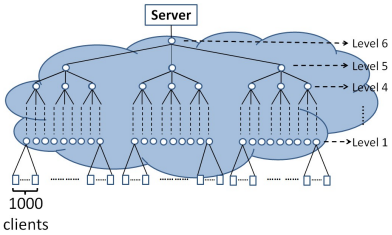


Fig. 6. Simulation Topology

of data is associated with a TTL which determines how long the data will be kept in the DS. Upstream routers monitor downstream routers' states and immediately remove the data when all downstream routers have had the same data cached. Algorithm 1 shows the above logic.

Algorithm 1 Coordinate Caching Algorithm

```
1: if the router is the root of a multicast group then
2:    TTL = BASE_TTL;
3: else
4:    TTL = extract_upstream_TTL(data);
5:    TTL = increase_TTL(TTL);
6:    if TTL > MAX_TTL then
7:       TTL = MAX_TTL;
8:    end if
9: end if
10: add_data_to_DS(data, TTL);
11: set_new_TTL(data, TTL);
12: forward_data(data);
13: if all_downstream_router_cached(data) then
14:    delete_data_from_DS(data);
15: end if
```

Section VIII-A evaluates the coordinate caching mechanism by comparing its performance with those of NDN and DONA.

VII. Scalability Issues

In this section, we discuss the scalability issues. We argue that the design of SIONA makes it a scalable system. This can be seen from the following aspects.

First, SIONA proposes a service/information separation scheme that splits the massive content space into services and information. Services and information are dealt with at different routing dimensions (inter-domain for service and intra-domain for information), which greatly decreases the scales of name spaces in each level.

Second, we believe that the quantity of services in the world is of the magnitude of today's fully qualified domain names (FQDN). The DNS system has proved itself with good scalability over the past decades. From the service point of view, using DNS provides good scalability.

Finally, while information is far more than services, it is only intra-domain propagated. It is well known that the principle of locality is widely applicable. The information required within a particular domain is much less than the total information in the world. Moreover, unlike IP address in current routing system, information will dynamically emerge and vanish. For instance, a real-time information may become useless after a particular time interval. As described above, a TTL value is used to control the information's lifetime in routers' RTs. As time goes on, new information is added and stale information is removed. This will strike a balance for RT tables that keeps their sizes within the necessary scale.

VIII. Evaluation

A. Caching Evaluation

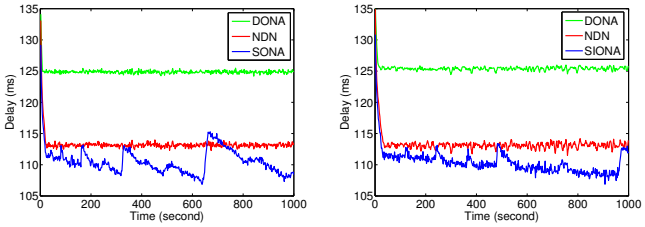
In this section, we evaluate our caching mechanism by comparing its performance with those of NDN and Dona. According to [4], we choose least-recently-used (LRU) as NDN's caching algorithm. As Dona does not specify a certain caching mechanism, we use LRU for Dona as well.

We built an event-driven simulator in *C*. We use the topology as is shown in figure 6. Each router is connected by one upstream router and three downstream routers. A server is set with 10,000 information files, each 1M in size. Each leaf router is connected by 1000 clients. Dona differs from SIONA and NDN in the sense that only the resolution handlers (RHs) provide caching functionality. In our simulation, we choose odd-level routers as RHs.

Each router has a cache of 1G. Each link is associated with a latency of 10ms. For every second, each client requests a file from the network according to a Zipf distribution. The simulation lasts for 1000 seconds. We record and compare the average delays of all clients to get the files in SIONA, NDN and Dona. Each SIONA router gains its own caching-TTL by doubling the TTL of its upstream routers.

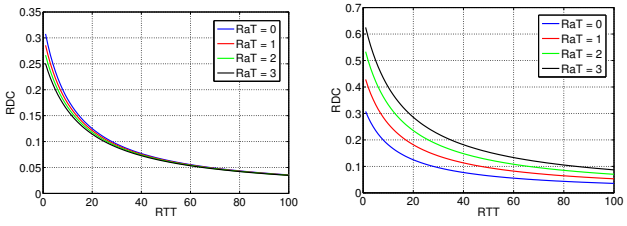
Figure 8 illustrates the results, with figure 8-a representing the results of base_TTL = 10 and figure 8-b representing base_TTL = 30. Both figures show that our caching mechanism significantly reduces the latency. For NDN and Dona, the latency quickly drops to around 113ms and 125ms respectively and remains steady as the simulation goes on, while the latency of SIONA keeps below 115 ms after the drop at the beginning and has an average of 110ms.

The reason why SIONA has a lower latency is that coordinate caching achieves better data dissemination among routers. This is because SIONA utilizes the buffer memory more effectively. For the same piece of data, upstream routers have a shorter TTL than downstream routers, thus expire earlier than downstream routers. This provides two advantages. First, when data is removed from the cache of an upstream



(a) base_ttl = 10 (b) base_ttl = 30

Fig. 7. Request Delay under different base_ttls
(The x-axis represents the duration of the simulation)



(a) RDC with cache hit (b) RDC with cache miss

Fig. 8. *Relative Delay Coefficients (RDCs)* of SIONA and Mobile-IP
(RTT represents the round trip time between the server and client, RaT stands for the time required by Mobile-IP to perform the handover registration and tunneling)

router, it is still kept by the downstream routers, thus content delivery won't experience a longer path. Second, the removed data leaves room for other contents which leads to optimal buffer utilization. The higher level a router resides in, the more downstream nodes it serves and the faster it refreshes its cache. This provides fairness for all nodes in the network, thus achieving better performance. It's not surprising that Dona has the highest delay because only parts of its routers (RHs) provide caching function.

It's worth noticing that the performance of the coordinate caching mechanism, while fairly good is not very stable. We believe that the concussion of SIONA's curve is due to the data expiration at the same rate (with the same base_TTL). However, theoretical analysis and extensive experiment/simulation are required to investigate the quantitative affects of different expiration intervals.

The latencies of DONA and NDN remain almost constant during the evaluation. This is because LRU doesn't experince sudden expiration and the distribution of coming requests doesn't change during the simulation.

B. Mobility Evaluation

In this section we use the same simulator to evaluate the performance of SIONA and Mobile-IP in the scenario as shown in figure 4. We investigate the recovery time for a client to recover the connection when handoff happens. We use *relative delay coefficient (RDC)* to represent the relative performance of SIONA and Mobile-IP, which is formulated by the equation 1. By this definition, SIONA will be superior to Mobile-IP if *RDC* is less than 1, and worse than Mobile-IP if *RDC* is greater than 1. Due to page limitations, we just briefly show the results (figure 8).

$$RDC = \frac{recovery\ time\ of\ SIONA}{recovery\ time\ of\ Mobile-IP} \qquad (1)$$

We can see from the picture that no matter cache hits or not, SIONA always outperforms Mobile-IP. Although the topology is simple, the simulation gives intuitive insights into SIONA's superiority in solving mobility problems.

IX. Conclusion

Information Centric Network (ICN) is an exciting area in future Internet research activities. This paper is a step to construct a feasible candidate for ICN. SIONA addresses the key problems of scalable content distribution by defining a name-based two-dimensional routing paradigm that directly supports effective content routing, caching and delivery. SIONA inherently supports mobility. It further supports multi-source multicast and network layer P2P, which provides efficient solution to massive data distribution. We develop a coordinate caching algorithm to optimize content delivery. Simulation results provide intuitive insights into SIONA's caching and mobility superiority. SIONA is on its way of evolution. We will keep on improving SIONA and take measurements using implementation, simulations and theoretical analysis to identify problems in the design and evaluate performances at different scales.

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