Language of Choice: On Embedding Choice-related Semantics in a Realizable Protocol

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***Abstract*—Choice-based future Internet architectures, in which choice is offered for fine-grained network services to different traffic flows, have been proposed in the literature. Such choice-based architectures have been envisioned in literature as realizing an economy of networking services that can give rise to a beneficial ecosystem of providers and consumers over time. Such an architecture would use an *economy plane* to allow service providers and customers to exchange information about available service alternatives, complete purchase and payment interactions, and use purchased services. While samples of such semantics have been proposed in these previous works, embedding them in specific realizations by defining messages to be exchanged and their syntax is a separate challenge, in which the needs for efficiency, ease of implementation, and extensibility, all need to be balanced. In this paper, we present the design of a possible embedding of the entities, and a functionally complete set of interactions, comprising a choice-based architecture. Further, to show the practical realizability of this embedding, we report on a prototype built on the GENI environment, and our experience in confronting real-world design issues. The prototype showcases new service models for value-added transport in such an architecture.**

I. Introduction and Problem

Even as the current Internet enables a range of services and distributed applications that grow ever broader and more variegated, several limitations of its architecture have become apparent as billions of humans and devices are connected through it. One key challenge is the discrepancy between the mechanisms by which technology is deployed in the Internet and the business models surrounding these processes. A root cause of such a mismatch appears to be that innovation in networking services, whether low in the layers such as device technology advancements, or high up as in forwarding or path computation innovations, has a long and hard road to deployed and available service offerings. From the network equipment designer and manufacturer's point of view, emerging technology is only worth building into boxes when they can guarantee interest from the customers of those boxes, namely ISPs and other network owners and operators. This typically means that the technology has to be quite mature. A mature technology is likely to be less costly, and also dependable enough that it justifies designing new network equipment to operate around it. The fiscal responsibility of the equipment vendor, unwilling to embark on risky ventures with technology whose real market impact is untested (especially in the face of a solid base of existing equipment, with demonstrated effectiveness), forms a natural brake for cutting-edge optical technology getting into network equipment. Following this problem further, we find that the ISP in turn is unwilling to deploy new technology without a clear understanding of how such technology can help justify the cost in terms of improved revenue or profit – again, especially in the face of an existing business model with existing services that are providing a healthy current revenue stream. This keeps the same sort of innovation explosion that the app market has seen from the networking arena.

We have previously put forth the proposition that an architectural enhancement to the Internet can allow such innovation to occur. We have considered the relevant issues in the course of our ChoiceNet project [1], [2], [3], [4], [5], [6], [7], under the umbrella of the NSF Future Internet Architecture program [8]. ChoiceNet is based on the economic axiom that *informed exercise of choice by customers (backed by money) can reward providers with good performance, select for them against providers who fail to provide good performance, and over time create an ecosystem of mutual benefit*. By introducing an "Economy Plane" that allows the presentation of competing offerings for various networking services, the formation of contracts for the various services can be devised to make up the entirety of a user's network needs. Most recently, we have reported in [9] on how the semantics for the required economic interactions for ChoiceNet can be designed.

In this paper, we address the problem of how to embed such semantics in a network protocol realization. There are several considerations to designing such a protocol, which are sometimes at odds. In Section III, we describe our design considerations in detail. Before this, we briefly describe the indispensible functions of the ChoiceNet economy plane.

II. ChoiceNet Architecture

The ChoiceNet project describes the introduction of architectural entities into the Internet to enable fine-grain economic interactions [1], [4], [2], [3], [5], and [6]. The goal of the ChoiceNet architecture is to enable competing service providers to provide service alternatives at whatever granularities they choose. Thus a traditional ISP can offer an end-to-end service alternative, without exposing its internal detail; however, a provider interested in offering a smaller unit of service (in which they are able to embed a value-added innovative component) can do so without having to support a complete infrastructure. Such service alternatives would need to be possible to compose together into the complete end-to-end service the customer requires. Such a possiblity is easy to see when differnet providers offer pathlet services that together make up the complete path the customer needs; however, such services may be far more general, for example, a provider could simply offer an encryption service at an intermediate point in the network that enables confidential to be sent over an untrusted segment of the network, or simply an observation service that the customer can use to verify that a source-routed path was indeed followed. The economic contract with the customer must be individually with the provider for each independent service, and it must be possible in principle for the customer to distinguish the performance provided by each provider hop, so that they may "vote with their wallet" to reward services that fulfill expectations, and penalize those that do not. Figure 1 shows the big picture of ChoiceNet. Every entity that other than the Customer is a provider of some service or resources.

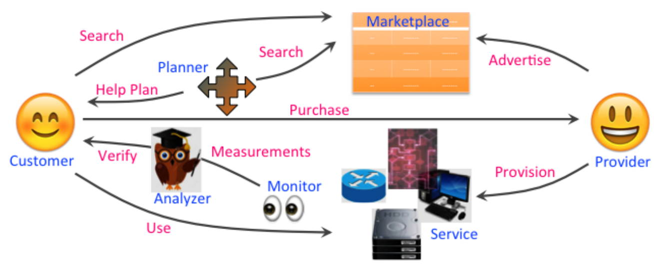

Fig. 1. ChoiceNet architecture

These interactions occur within ChoiceNet's economy plane, that offers the presentation of competing services from various providers, the formation of contracts with each of these providers to satisfy a customer's service requirements, and the verification of performance between contracted services. Transactions occurring within ChoiceNet's economy plane would parallel real-world interactions that take place between service providers and customers. Contractual agreement are formed between service providers and customers using a defined set ChoiceNet Interactions after some payment (or suitable consideration are exchanged) has been fulfilled. A successful payment result with the customer receiving a *token* of some kind. The token would be be used authorize access to paid services within the "Use Plane". Figure 2 shows a scenario where the path required by the customer is provided by composing pathlet services from three different network providers, and the customer must make separate contracts with each of them. In addition, the customer desires measurement services where the network providers hand off the customer's traffic to each other, and makes contracts with the provider of each such monitoring service. Finally, the customer relies on an analytics service provider to analyze the measurements for value-added services, such as detecting performance failures, or predicting likely future failures.

The three main entities which participate in the economy plane are the Service Providers, Marketplace, and the customer (service user) . A **service provider** describes a general concept of a provider that offers a service. A service provider could provide various number of service such as transit, forwarding, encryption, storage, and etc. The **Marketplace** is a service

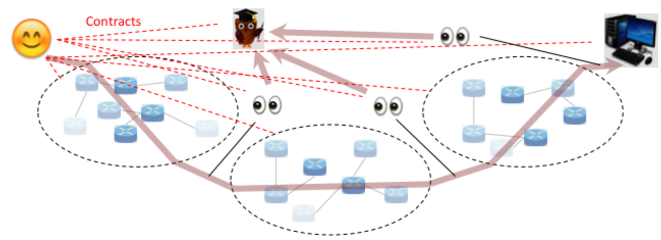

Fig. 2. ChoiceNet contracts

provider that offers a listing capability. The marketplace acts as a centralize service for customers to discover published service advertisement. In a system supporting choice-based network architecture, a marketplace could offer its service to a single vendor or could open it to multiple vendors. There are no limitation or restrictions on the business model employed by an entity serving this role. For the prototype discussed in this paper, the marketplace offers its listing capability at a cost to service providers but allows customers to query its system for free. In order for service providers to know the cost for listing an advertisement, the marketplace must advertise their listing service. **Customer** is an user that consumes a service. A customer queries the marketplace to discover services that can fulfill their need. Each customer may have their own strategy for composing a service that fits their service requirement. A customer is not limited to only being an end-user. A service provider requesting on the cost of using a marketplace listing service, is a customer to the marketplace.

III. Design of ChoiceNet Semantic Language and Protocol

We have previously presented a semantic language for ChoiceNet to complete a minimum complete set of economy plane interactions. Such semantics constitute a definition of the data model, but they must be actually realized by some specific bits-on-the-wire protocol. Conceptually, there can be many such embeddings, and they are all equally ChoiceNet. In practice, different encodings will have different characteristics.

In designing the protocol we present here, we considered (i) ease of message representations on the wire and in memory, and ease of translation between the two, (ii) human-readability, since this is an initial prototype which is likely to be subject to revision, (iii) easy extensibility of the ChoiceNet language, since it will need to grow as different services we do not envision today are offered in the future, (iv) ease of assigning identity and provenance to messages, since accountability and verifiablity are at the core of ChoiceNet.

Each ChoiceNet message, in our proposed scheme, consist of a set of fields, individually called ChoiceNet Message Field, that contains 3-tuple structure; *Attribute Name*, *Value*, and *Vocabulary URL*. The *Attribute Name* describes the field's header and the *Vocabulary URL* describes the location for the field's definition. The *Value* can contain a literal or another ChoiceNet Message Field(s), allowing it to be hierarchical. A ChoiceNet

Message contains the following ChoiceNet Message Fields Version, Originator Name, Originator Signature, Originator Type, Message Type, and Message Specific Field. Figure 3 illustrates a basic ChoiceNet Message. Version defines the ChoiceNet Semantic Language version being used by the message. Originator Name, Originator Signature, Originator Type describe the entity's name, security signature, and the ChoiceNet Provider type, respectively. Message Type describes its type and Message Specific has the payload for that message type. Each ChoiceNet messages are encapsulated within an Extensible Markup Language (XML) payload and are currently transported within an User Datagram Packet (UDP), though any transport protocol would be permissible. Each message were left in clear text but in a real implementation, the content would need to be secure. We assume a public key infrastructure may be available otherwise by using certifying authority and X509 certificates, as normally done to secure transactions over the Internet.

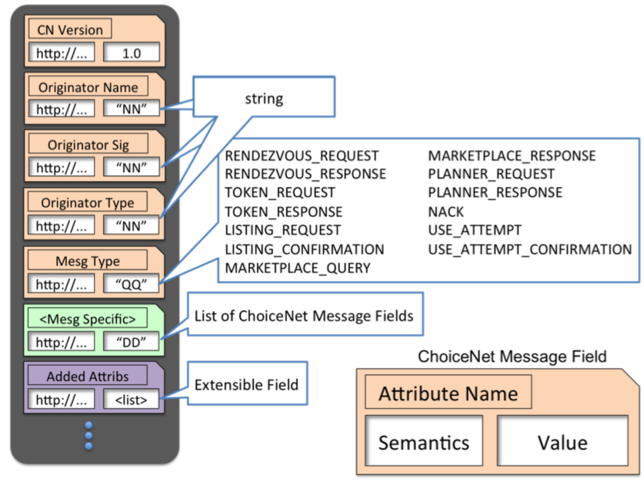

Fig. 3. ChoiceNet Message Structure

A. ChoiceNet Interactions

The ChoiceNet protocol design are based on the most elemental approach where each interaction (except Negative Acknowledgment) performs a request/response message that satisfies their purpose for a minimum set of ChoiceNet agents. With each message containing the minimum required fields to satisfy the intent of the message. This approach offered the greatest flexibility in allowing multiple different ChoiceNet entities the opportunity of using the same set of messages. The following list comprise the minimum set of interactions defined and their purpose.

- Rendezvous Interaction: ChoiceNet Entity Discovery mechanism
- Purchase Service Interaction: Retrieve service authorization token
- Advertise Service Interaction: Service Advertisement Provisioning Operation
- Marketplace Query Interaction: Performs lookup searches for a given query and supplies list of matching services
- Planner Interaction: Retrieve feasible service composition based on a given service requirement
- Negative Acknowledgment Interaction: Inform Recipient of Malformed/Incorrect Message
- Use Attempt Interaction: Activate the provisioning of a paid service

Negative Acknowledgment Interaction cover a class of responses for handling operations that do not respond correctly within the other interactions, such as a Malformed/Missing field. For example, a negative acknowledgement will be during a Use Attempt Interaction, if the customer supplies an incorrect token.

B. Formation of a ChoiceNet service contract

Our prototype focused on minimal set interactions necessary to have a complete Economy plane. The necessary sequence of interactions that will result in a customer successfully purchasing and activating a service demonstrates the formation of a service contract. This involves five of the interactions and the exchange of 12 messages within the Economy plane. Figure 4 illustrates the necessary sequence of interactions. It is assumed that each entity initializing communication already knows about that entity and what role that entity is serving through a Rendezvous message. This initial Rendezvous message is not shown in the figure.

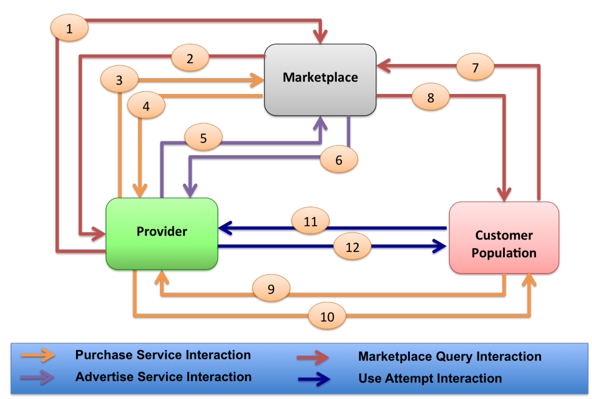

Fig. 4. Core ChoiceNet Protocol Interactions

1) Marketplace Query Interaction: Service Provider requests cost information for listing a service
2) Marketplace Query Interaction: Marketplace responds with a list of advertisements that match the provider's query.
3) Purchase Service Interaction: After the service provider has made payment with the Marketplace's third party payment portal.
4) Purchase Service Interaction: Marketplace verifies the provider's proof of purchase and responds by issuing a token to list a service
5) Advertise Service Interaction: The service provider supplies the token and the service advertisement they wish to list within the Marketplace, to the Marketplace.

6) Advertise Service Interaction: A confirmation of the provider's service being listed
7) Marketplace Query Interaction: Customer requests information about pathlet services
8) Marketplace Query Interaction: Marketplace responds with a list of advertisements that match the customer's query.
9) Purchase Service Interaction: After the customer has made payment with the Provider's third party payment portal.
10) Purchase Service Interaction: Provider verifies the customer's proof of purchase and responds by issuing a token to activate using the pathlet service
11) Use Attempt Interaction: Customer request's to activate the purchased service by supplying the appropriate token and firewall specification for his traffic.
12) Use Attempt Interaction: On success, a confirmation message is sent to the customer and the customer may send traffic successfully through the provider's network.

Note, that before a Purchase Service Interaction can be successfully performed, ChoiceNet agent requesting a service must contact the service provider's payment portal and make the appropriate payment for the advertised service. In our prototype, each ChoiceNet agent had an account with a mutual third-party payment service (Paypal and Bitcoin payment portal like Coinbase). The receipts from this outside interaction are used as the proof of purchase value that the customer must supply the service provider in order to receive a token to use their service.

C. Service Provisioning

Provisioning is an internal process performed by a service provider and takes place within the Control Plane. In our current implementation service provisioning can take place in two ways, both the Advertise Service and the Use Attempt Interactions are interactions that involve provisioning a paid service. Both interaction require a valid token to authenticate the client's right to use the resource along with specification that must be operated on. In the case of Advertise Service Interaction, the specification is the provider's service advertisement such as the ones discussed in [9], while the Use Attempt Interaction's specification contains firewall-like rules for filtering and routing the customer's traffic. In other words, this firewall specification informs the provider what traffic characteristics should be allowed through its network and how it should be routed (next hop). Specifically, by describing the appearance of the packet headers with a parameter that describes the next hop location. Listing 1 provides an example of what a firewall specification may contain. The specifications are input in the Economy Plane but are supplied to the ChoiceNet agent's Control Plane for processing.

D. Service Composition

The only interaction not required in forming a service contract but has been defined is the Planner interaction. The Planner interaction handles discovering viable service alternative based on a given service requirement and occurs between a customer and an ChoiceNet entity known as a Planner. The planner uses the service advertisement as a service primitive to compose feasible service recipes from third-party service providers' advertised services. Advertised services stored within a Marketplace, provides a planner service with the available network resource and functionality being offered from a host of third-party service providers. These advertised services must adhere to some standardized semantics to allow service compositions between multiple third-party service providers. We have investigated and prototyped a minimum example on GENI [9][10]. A planner's service composition contains the Advertisement ID and the provisioning parameter necessary to connect one service to another. Advertisement ID identifies the advertisement within the marketplace, while the provisioning parameter informs the customer how they should tell the provider to route their traffic. Listing 2 provides an example of what a feasible recipe received as a response for a service requirement. In this example, the provisioning parameter gives the next hop address a customer should have their traffic forwarded towards within a service provider's network. The provisioning parameter can be envisioned to provide additional fine-grain management operations for composing services between providers, for example managing how lightpaths should be established between multiple optical network providers for a customer's flow [9].

E. Design Considerations

The ChoiceNet protocol discussed here is intended to work on top of any existing transport protocol. Any caveat about the underlying protocol are not handled by the ChoiceNet protocol, for example packet loss occurring for a connectionless protocol like UDP is expected to be handle by the application. With the current transport protocol choice, any request transferred lost does not have a negative affect on the client and the option to resend a message still exists. A lost response can result in the recipient receiving duplicate requests and may result in the user receiving a copy of the lost response or a negative acknowledgment due to duplicitousness of their request. The negative acknowledgment message would

```
<firewallSpecification>
    <action>ACCEPT</action>
    <addressVersion>IPv4</addressVersion>
    <destinationAddress>ANY</
    destinationAddress>
    <destinationPort>ANY</destinationPort>
    <protocol>ANY</protocol>
    <sourceAddress>10.1.10.1/32</sourceAddress
    >
    <sourcePort>ANY</sourcePort>
    <provisioningParameter>10.1.23.3</
    provisioningParameter>
</firewallSpecification>
```

Listing 1. Use Plane Firewall Specification

```
<recipe>
 <cost value="71" />
 <serviceAdvertisements>
  <advertisement identifier="08
   e19dc233f20ca274dd1c2270003dca"
  provisioningParameter="10.1.10.1/32" />
  <advertisement identifier="08
   e19dc233f20ca274dd1c22700050df"
  provisioningParameter="10.1.12.2/32" />
  <advertisement identifier="08
   e19dc233f20ca274dd1c2270006875"
  provisioningParameter="10.1.2.50/32" />
  <advertisement identifier="08
   e19dc233f20ca274dd1c22700085df"
  provisioningParameter="10.1.23.3/32" />
 </serviceAdvertisements>
</recipe>
```

Listing 2. Service Composition Recipe

contain the reasoning for the message and should resolve that the client's intention was made.

Other interactions were considered but were abandoned from our initial prototype due to their purpose overlapping existing interaction for example a Subscription interaction, which would allow providers to monitor changes of advertised services within the Marketplace. This interaction can be viewed as an enhanced version of a Marketplace Query Interaction with the ability to issue a polling frequency for brief information detailing any changes. A broker ChoiceNet entity who had existing contractual agreement between several providers for some resource, would be in a position to repackage the resource to resale composed services through multiple providers. While such a subscription interaction could prove useful for a broker, for an initial prototype this operation can be resolved by performing continuous queries to the Marketplace and would require the broker to perform the detection itself.

The contract discussed above only involved a single service provider and would need to be duplicated if multiple service providers were required to meet a customer's end-to-end service request. This offers an incentive for a third-party ChoiceNet agent to market composition services along with accepting the responsibility of forming such contract on the behalf of a customer. For such an entity to exist, an additional ChoiceNet message field would need to be available to handle delegation. This message would be handled as an extensible field, as its operation is only requested for this single entity. Due to the limitation of this use case, it was not included in our prototype.

IV. Proof of Concept Prototype

Our prototype contains a deployment that fully realizes the formation of an 'Economy Plane' contract and allows for the propagation of data within that contract's 'Use Plane' resources, after a contract has been finalized. This prototype also demonstration of composed service consisting of multiple providers. The prototype consisted of four service providers, a Marketplace, customer, and a third-party content server. Among the service providers, a single provider is solely provides a composition (planner) service, while the remaining providers demonstrate network providers offering pathlet services. An intermediate network service provider also offers transformation services, specifically substring-specific payload modification and packet logging. The topology for this system is illustrated in Figure 5. In this figure the 'Use Plane' is split into its two component planes; data and control plane. The goal for this deployment was to both validate that through using the current set of ChoiceNet Interactions, a customer could successfully send traffic through the network service providers to a connected content server and verify that our composition service could compile feasible service recipe with the given information in the Marketplace. To demonstrate the efficacy of the prototype, it was deployed on GENI with each of its entity and data plane resources within separate virtual machines. This GENI prototype was demonstrated at the 23rd GENI Engineering Conference, Urbana-Champaign, and the Infocom-Live demonstrations at IEEE Infocom, 2016, San Francisco.

The Marketplace in this prototype is running CouchDB, NoSQL database that stores data with JSON documents. Traditionally a user would query CouchDB documents over HTTP, but in order to keep communication within the defined context of a ChoiceNet Message, a ChoiceNet agent was deployed along side with the database. This agent internally speaks to CouchDB and sends the content wrapped within a ChoiceNet Message. To perform a IP subnet searches within an advertisement, the ChoiceNet agent translates slash notation queries into a format CouchDB can search with. This added functionality was made to reduce the potential number queries a customer (specifically a Planner) would need to perform to find whether a service exists in the Marketplace.

Each network provider were equipped with a programmable Software Defined Network (SDN) switch, specifically LINC, attached to allow granular control over the network using an out-of-band third party controller software, Ryu [11]. When a customer completes the exchange of the 12 messages

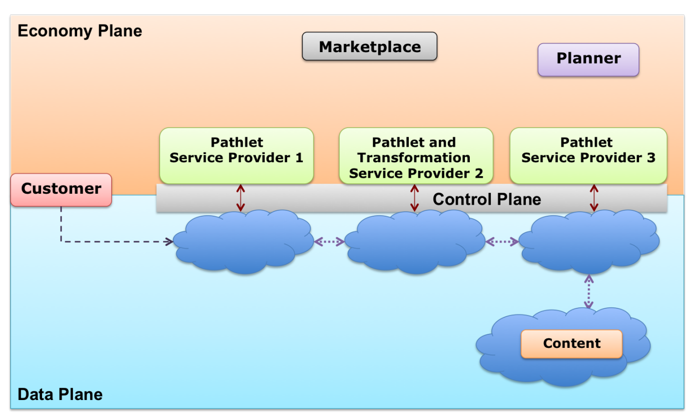

Fig. 5. ChoiceNet Demo Topology

discussed in Section III-B and sends a valid request to activate the provisioning of their service, the provider's economy plane agent sends the firewall specification (along with the valid token) to his SDN controller. The controller assesses the specification and adds a corresponding OpenFlow rule based on the content of the specification. For this prototype, the time span of the rule is based on the expiration value of the token. The service provider offering a transformation service uses a simpler version of the External Processing Box (EPB) [12] to perform the substring-specific payload modification and packet logging. Our demonstration used a simplified version of the EPB to demonstrate an in-flight transformation service. Specifically, this in-flight service provided payload modification and used deep packet inspection (DPI) to perform an operation when a substring was present in the payload. Other services enabled by the EPB such as its multipath service, could be offered by a service provider to provide payload matching traffic with higher QoS through its use of redundant paths. By default traffic sent to a network service provider's 'Use Plane' network prior to an accepted Use Attempt Interaction occurring within the 'Economy Plane', are dropped by the network. Only after this interaction is successful and a firewall specification is supplied that appropriately matches the customer's traffic headers, will the traffic be allowed to traverse the provider's network.

Service providers advertised their suite of services within the Marketplace for customers to discover and potentially purchase. With this deployment and the set of services, we demonstrated all possible end-to-end services with the combinations of advertised services; pure transit services, transit services with payload modification, transit services with packet logging, and a transit service with both payload modification and packet logging.

V. Related Work

As envisioned by the authors of ChoiceNet, many ChoiceNets may exist with different protocol structures and order of operations. Our approach involved using enriched semantics that considered the interactions between different ChoiceNet entities, while also allowing for flexibility in service offerings. The ChoiceNet system described in [13], on the other hand relies on NetFilter Queue to capture the initial customer packets per connection to begin the Economy Plane interactions. The interactions follow the same paradigm as the interactions discussed here; offering service choices through a Marketplace, requesting payment, and provisioning the service. The Marketplace prototyped in [13], serves as a central authority for validating payment and authorizing the provisioning of services, while our prototype's Marketplace only duty is to serve as a listing repository for network services and a service provider are responsible with validating payments and provisioning services. The approach in [13] is reasonable for a single service provider with their own Marketplace, but it does not discuss service offerings from multiple providers. This limits the opportunity for third party ChoiceNet agents (such as the Planner) from being able to supply composed service alternatives on demand. These alternatives would further diverse the pool of service offerings available to customers by stitching multiple service providers' offerings together to satisfy a single demand, as demonstrated in our prototype.

VI. Conclusions

This paper discussed the architecture design for a choice-based network and the minimum set of economy plane interactions required to complete a service contract, and specifically addressed the challenge in designing an extensible messaging system, its syntax and format, and implementing it to demonstrate communication between ChoiceNet entities. We have demonstrated these concepts with the working prototype implementation on GENI described in this paper.

VII. Acknowledgements

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