Service-Based Computing for Agents on Disruption and Delay Prone Networks

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1. INTRODUCTION

As computing and communication hardware becomes smaller and more powerful, computer networking is being applied to a wide array of problems and settings. The ubiquity of wireless Internet access in urban society is just one symptom of this advance. However, in many domains the nature of the network is significantly unlike that of traditional wired networking. Common assumptions regarding properties such as delay, connectivity models, and hosts often do not hold, posing many new challenges to be addressed. Two archetypical settings highlighting these are *Interplanetary Internet* and *mobile ad-hoc networks*. The network layer alone cannot resolve many of these issues—it is not possible to completely shield the application layer from factors such as long delays and frequent disconnects. Agents in these settings cannot behave as they would on a wired network and achieve similar performance. Developing effective agent-based systems for these environments therefore requires new approaches, techniques, and agent behaviors to account for these constraints.

Domain Challenges. A number of distinctive properties can be identified in the domains mentioned in the introduction, including: latency, bandwidth, link errors, asymmetric links, low connectivity, and others [1]. Of course, these domains also include a number of common properties found in other environments as well. An implication of all these constraints is that the expectations and abilities of agents and applications are very different in these domains. Agents must take an active role in their usage of the network and other resources. Only by sensing network state and other environmental properties may agents efficiently utilize scarce resources, operate under adverse conditions, and recover from failures.

Approach: Mobile Agents and Services. Many of the challenges of these domains may be addressed through mobile agents utilizing service-based computing. What this approach does provide is the capability for arbitrary, en route decision making as messages traverse the network. By perceiving and reasoning on properties of the network and other aspects of the environment, agents may efficiently utilize available resources and respond to changing conditions. Under this approach, communications between static agents, servers, and other application-layer entities are delivered by mobile messenger agents. This supplants direct packet-based exchanges, enabling efficient resource utilization and adaptation to changing conditions. These agents act as proxies for the sender, providing them the ability to direct message progress. In direct packet-based schemes, only routers have input during message transit. The ability of the application to parameterize and control traversal is also limited and reliant on fixed infrastructure, hindering flexibility and customizability. Further, faced with the constraints present in these domains, it is impossible for the senders to react effectively to environmental changes. Agent messengers are uniquely able to do so through their ability to make intelligent decisions throughout network traversal. Enabling agents to reason, plan, and react to a dynamic world requires the ability to sense and perceive that world. This problem is addressed in this approach using service-based computing. Services are agents, servers, and other software that publish descriptions of their capabilities, roles, and interfaces. Agents search and reason on these descriptions to discover available services and guide automated interaction with those providing desired functionality. Importantly, knowledge of available services is itself a significant percept. Agents traveling to specific targets are subject to required services becoming unavailable through events such as host outages, transmission delays, and link disruptions. Disseminating knowledge of available services allows agents to search for alternatives and respond to such failures.

2. SCENARIO: SATELLITE RELAYS

This section presents a scenario drawn from the Interplanetary Internet, illustrated in Figure 1. At the core, the scenario consists of two communicating surface hosts, A and D, and two relay satellites, B and C, as shown in Figure 1(a). The two satellites are in polar and equatorial orbit and periodically come within range of each other and one of the ground hosts[1]. At no point is there end-

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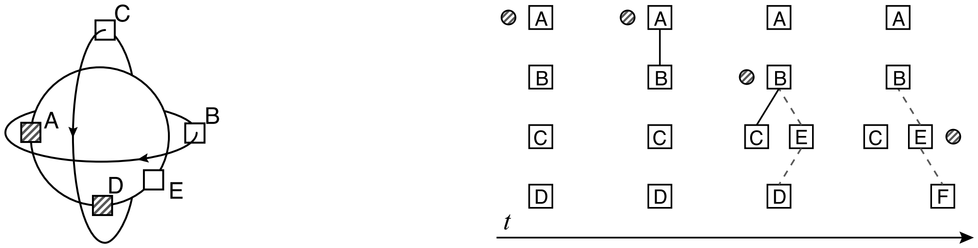
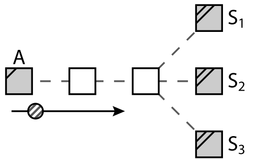
[1] Initial setup of two satellite and surface hosts mentioned at [2].



(a) An arrangement of surface and satellite hosts, aligned along perpendicular axes.

(b) Host E is intermittently available. Host D becomes permanently unavailable during message transit to host E, while host F simultaneously becomes available.

Figure 1: A planetary network configuration with no end-to-end connectivity, but a viable communications path.



(a) Agents are sent from host A toward the services on S_i.

Agent Type	Success
Packet	47%
List Target	73%
Early Binding	62%
Late Binding	86%

(b) Agent success rates with each service independently available 50% of the time.

Agent Type	Success
Packet	18%
List Target	33%
Early Binding	20%
Late Binding	46%

(c) Agent success rates with each service independently available 20% of the time.

Figure 2: Demonstration of service knowledge applied to the scenario from Figure 1.

to-end connectivity between hosts A and D. Any messages between them must be stored and then forwarded as links become available through the movement of the orbiting relays. Most work on Interplanetary Internet is based on this concept of storing and forwarding messages, which are typically larger than Internet packets and referred to as bundles. The sequence of links becoming active and the message being forwarded is shown in Figure 1(b). If a host or link appears during message transit, a routing decision point is created. An example is the appearance of an unreliable but fast bridge between satellite B and host D through host E. The decision to use this bridge relies on the transmitting agent's prioritization of speed versus reliability. It might be appropriate to use the bridge if the message is simply an informational update on position or status but if the message instead contains important data, satellite B should wait and forward the message to satellite C. Fixed routing infrastructure will not be able to parameterize all possible decision criteria. Further, host D might permanently disconnect during message transit, as in Figure 1(b). A fixed-target message would then fail, although there might be equally suitable recipients like host F which appears after the message arrives at E. If the message in Figure 1 were an agent acting as a proxy for the sender on host A, intelligent decisions could be made en route to address these problems. At host B it could apply appropriate reasoning to determine whether or not to use the newly discovered link. The agent could also make the decision to migrate to host F upon the failure of host D, preventing the waste of the bandwidth, time, and power already spent forwarding the message.

Demonstration. Figure 2 demonstrates the benefit of using service knowledge to search for alternative destinations. A small simulation was performed using MATES, an open-source, lightweight, discrete-event agent simulator [3]. Four types of agents were spawned at host A in Figure 2(a) with the goal of finding a particular service, available on S_1, S_2, and S_3. Links were reliable but the hosts S_i were periodically, independently cycled through periods of availabitily. The length of each period was randomly determined within the ranges up_{min}–up_{max} and down_{min}–down_{max}. Table 2(b) gives results with each service available 50% of the time: $\text{down}_{\text{min}} \equiv \text{up}_{\text{min}}$; $\text{down}_{\text{max}} \equiv \text{up}_{\text{max}}$. Table 2(c) gives results with each service available 20% of the time: $\text{down}_{\text{min}} \equiv 4 \cdot \text{up}_{\text{min}}$; $\text{down}_{\text{max}} \equiv 4 \cdot \text{up}_{\text{max}}$. These results are averages over more than 11,000 agents per class. The four agent classes had the following behaviors: 1,*Packet Agent.* Always travel to host S_1, failing if that host becomes unavailable at any point; 2, *List Agent.* Attempt to reach either host in the a priori list $\{S_1, S_2\}$, failing if both are ever unavailable; 3, *Early Binding Agent.* Consult the service registry before leaving host A and choose a target host offering the service. Fail if it ever becomes unavailable; 4, *Late Binding Agent.* Consult the service registry at each step and migrate toward a host offering the service. Fail if at any point there no such hosts. The results in Figures 2(b) and 2(c) match well against expectations: the packet and list agents succeed at nearly the availability of their targets. Performance of the early binding agent correlates strongly to the probability that the host it chose would remain available until the agent arrived. The late binding agent fails at close to the probability of each S_i being down simultaneously. This simulation makes three important assumptions: correct network topology is instantly, globally available; correct service knowledge is instantly, globally available; service matching is instantaneous.

3. CONCLUSIONS

This paper presents several emerging domains and applications posing significant challenges to agent-based systems. The argument is made that even under optimal networking, effective agents in these environments must perceive, reason, and act on conditions such as network state. By identifying challenges and an approach to their resolution, it is hoped that this paper contributes to the development of effective agent-based systems for these domains.

4. REFERENCES

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