Towards Data-Driven Declarative Networking in Delay Tolerant Networks

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ABSTRACT

A Delay Tolerant Network (DTN) provides content storage as a core network service across applications to deal with intermittent communication. Thus, the DTN realizes content-based networking, where messages flowing within networks are at content level, rather than at packet level and focus on information dissemination rather than on node delivery. In the Haggle project, which is a type of DTN, we manage to implement publish/subscribe semantics with an event-driven and asynchronous operation into a kernel component for enabling efficient distributed content storage. We are working towards an integration of declarative networking to Haggle for data-driven declarative networking.

1. DATA-DRIVEN NETWORKING

The Internet has transformed the way we seek information, but it requires strong connectivity with no tolerance to disruption. The recent emergence of Delay Tolerant Networks (DTN)[4][9] brought a different communication paradigm, which is decentralized and distributed over a multitude of devices that are dynamically networked, carried by people, and embedded in everyday life. As people move around, they can exchange messages with nearby devices, carrying a message until it is close to another device. This leads towards a global mesh network of devices, and digital traffic can flow without infrastructure. Such devices are sparsely distributed so that networks are often partitioned due to geographical separation or node movement.

The architecture of the Internet cannot satisfy this new type of communication, since traditional TCP/IP networks rely on stable end-to-end (e2e) connectivity, and locator-based access relies on stable connectivity to naming, caching, and search infrastructures to deliver data successfully. Nevertheless re-architecture of the Internet has been under hot discussion [7][5]. Interestingly, the challenge of DTN bundle protocol [6] to the traditional layering strategy of the Internet protocol has recently been discussed. The DTN bundle protocol includes cross layering functionalities such as forwarding and dynamic routing, retransmissions and persistent storage and application metadata tagging within the same protocol.

When the network is partitioned, there are two distinct directions to deal with: 1) epidemic dissemination to increase the probability of delivery, and 2) store-and-forward type overlay functions for dealing with disconnected operations and aiming at opportunistic data dissemination. DTNs provide content storage as a core network service across applications, while traditional networking treats storage as an application layer property. This significantly differs from middleware or application overlay, where storage and routing mechanisms are managed together. This radical departure from traditional networking makes content-based networking being enabled, where messages flowing within the networks are at content level, rather than at packet level, focusing on information dissemination rather than delivering to a node. The functions include search, caching, networked storage, synchronization, and so forth.

We have introduced the Haggle project [8], which is a type of DTN focusing on Pocket Switched Network (PSN). In PSNs people carry devices in their pockets, which communicate directly with other devices within their range or with infrastructure. Haggle takes a layerless networking architecture that incorporates publish/subscribe semantics with an event-driven and asynchronous operation.

In DTN environments, people want to get information on shops rather than a connection to shop websites. Instead of reaching a search engine to look for managed web content, directly searching the network for content is the goal. This is a radical change for the network operation and shares goals with declarative networking [3]. Thus, we are looking into the integration of declarative networking to Haggle and providing declarative network in Datalog type of languages to compile them into executable dataflow programs. The declarative approach will improve the simplification of operation, and robustness on routing protocol, replication, overlay construction, indirection and so forth.

An important issue here is to provide sufficient expressiveness and semantics for event processing within the language definition, where vast research in past decades on event-based middleware can contribute ranging overlay construction to event correlation and publish/subscribe middleware can meet the core networking components.

This paper continues to describe event driven design of Haggle in Section 2 followed by the declarative networking in Section 3 and concludes in Section 4.

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2. EVENT DRIVEN KERNEL

Haggle's overall objective is to provide functions for delivering, searching, and retrieving data over the networks in DTNs, and a data-driven architecture [1] is implemented. Haggle takes a layerless architecture and a modular approach is facilitated, where managers (e.g. Data Manager, Security Manager etc. [8]) provide functions and interfaces to communicate with applications and other managers. The core component is called the *kernel*, which processes events from an event queue. Events are fed by applications and *managers*. The semantics of publish/subscribe and an event-driven and asynchronous operation are equipped. The kernel maintains a shared data structure, and managers implement the functional logic with it. The managers are unaware of each other and interact over the event queue using predefined public events. Managers can hence easily be plugged in and out of Haggle. The logic implemented by a manager depends on the task of the manager, and the abstract interface of the manager has to be well-defined.

Haggle currently defines a unified metadata format for applications, which is expressed in XML. For example, the metadata is used not only for local searching, but also as a generic header for forwarding data between devices. As such, Haggle does not use *traditional packet headers* that define addressing schemes and multiplexing/demultiplexing. Instead, the metadata itself defines the *address* and searching and filtering on metadata are operations that determine how data is forwarded. Thus, applications can automatically take advantage of any connection opportunities that arise, both local neighborhood opportunities and connectivity with servers on the Internet when available.

The data on each node in Haggle must be visible to and searchable for by other nodes (with appropriate security/access restrictions applied). A piece of application data along with its metadata in Haggle is simply called a data object. A data object can also have zero length data, i.e., it is only metadata. This makes it possible to use data objects also for signaling and control messages. Haggle is hence data centric with the data object as the basic communication element that is always handled in the same way using the interfaces provided by the Haggle architecture. Persistent storage of data objects is supported through a data store.

The current metadata based on purely attributes may not provide sufficient functionality such as more sophisticated event structure, filtering mechanism, security and so forth. Content-based subscription with temporal, geographic and authorization could be added. Event advertisement, subscription, rule-based content management including forwarding, caching, and deleting can also be considered. The metadata operations will be complex along the size of the network and complexity.

Here, we propose integration of declarative approach to a core component (i.e. Haggle kernel) for routing, naming, and policy extending content-based networking in DTNs.

3. DECLARATIVE NETWORKING

A declarative networking uses declarative languages to define a search function described 'what to look for' and complies into distributed data flows. The declarative approach can take away many complexities that arise during networking and data processing.

In the Internet, the P2 project [3] has shown that declarative logic languages can describe many overlay network construction and Internet routing protocols. In [2], Chu *et al.* introduced a Declarative Sensor Network (DSN), where the high-level declarative language is applied to data acquisition, dissemination and resource management, while retaining architectural flexibility. They demonstrated that a wide variety of ad hoc sensor network protocols can be specified declaratively in a compact way.

In DTNs, forwarding mechanisms are driven based on predicates/constraints derived from the dynamic network state or observed network characteristics. Observed mobility and social connectivity at a node can be described in the declarative language (e.g. Overlog/P2) producing a fragmented code, which can be used for processing data distribution. Thus, it can be seen as a distributed evaluation of a P2 program that limits battery or wireless link use but maximizes coverage of interested nodes with given content. Our aim is to build a declarative network with an expressive language for DTNs, where potentially more complex event structure and node functions are required than the sensor networks.

In DTNs, the basic communication model includes one-to-one, many-to-many, and many-to-one and communication will be symmetric [10]. This symmetry allows receivers to filter out unwanted information and lets senders target information to a subset of receivers. For example, senders might want to send information only to potential receivers in New York. The message can contain an active-attribute that describes the actual information of the receiver.

4. CONCLUSIONS

In this paper, we introduce a new vision of networking in DTNs: Data-Driven Declarative Networking, where communication resources are managed together with network connectivity towards enabling content-based networking. We envision such declarative networking in Haggle, which aims at a node architecture rather than a routing protocol. We are working on the integration of the declarative language to Haggle.

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