PhotoNet: A Similarity-aware Image Delivery Service for Situation Awareness

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ABSTRACT
This demonstration illustrates PhotoNet, an image delivery service for mobile camera networks. PhotoNet is motivated by the needs of disaster-response applications, where a group of survivors and first responders may survey damage and send images to a rescue center in the absence of a functional communication infrastructure. The protocol runs on mobile devices, handling opportunistic forwarding (when they come in contact) and in-network storage. It assigns priorities to images for forwarding and replacement depending on the degree of similarity (or dissimilarity) among them. Prioritization aims at reducing semantic redundancy such as that between pictures of the same scene taken from slightly different angles. This is in contrast to redundancy among identical objects and among time series data. We evaluate PhotoNet in an emulated disaster recovery scenario, with a predetermined set of problem locales that need attention. Humans with camera phones form a mobile camera sensor network. Not all pictures make it to the rescue center because of resource constraints. At the rescue center, the utility of the camera network is measured by the number of problem locales of which the center becomes aware as a function of time. A better network delivers awareness of more trouble locales sooner. We show that, in resource-constrained networks, reducing semantic redundancy can significantly improve utility. Users of the demo will be allowed to interact with both a simulator and a small set of mobile phones to understand the impact of network and protocol parameters on situation awareness.

Categories and Subject Descriptors
D.2.5 [Software Engineering]:

General Terms
Design, Reliability, Experimentation

Keywords
Data fusion, Participatory sensing, Quality of information

1. INTRODUCTION
In this demo, we illustrate an image collection and delivery service for participatory (photo) camera networks. The service is geared for disaster recovery scenarios where it can take content from mobile devices (such as camera phones) in the possession of survivors and first responders, and deliver it to a command or rescue center. In such scenarios, we assume that infrastructure (such as power and cell towers) is down, making communication possible only opportunistically between nearby wireless battery-operated devices. As such nodes move, data spreads, leading to a disruption-tolerant network (DTN) model. The focus on photos is motivated by the proliferation of mobile camera phones. Pictures make a good compromise between expressiveness and resource needs. We show that by reasoning about semantic similarity between images, one can make significantly better use of scarce communication resources thereby substantially improving overall situation awareness at the sink. The demo is based on a paper by the authors, currently in submission to ICDCS [2] (which itself does not have a demo session).

The main contribution of PhotoNet is to reduce content redundancy. New content that is deemed similar to previously encountered content receives a lower priority. By maximizing delivered content diversity, the network has a better chance at giving the sink the “big picture” quicker, as opposed to delivering lots of pictorial coverage of more populated locales and none on more isolated ones. We borrow mechanisms from vision literature [1] to determine visual similarity between communicated images. These mechanisms become key to assigning message priorities.

Besides being content-aware, our similarity-based message prioritization scheme bears another interesting difference from traditional traffic prioritization schemes discussed in network QoS literature. Prior schemes associate priority with each message independently (e.g., based on its content type, class, source, or destination). Instead, we consider the relations between different objects in assigning priorities. Specifically, we maximize a measure of distance between reported objects, hence favoring delivery of dissimilar content.

Understanding relations between objects is a necessity, not choice, whenever sensor network utility is not additive in the utilities derived from delivery of individual sensed objects. For example, delivering the first picture of a new damage scene may have high utility. Yet, delivering the second picture of the same scene has lower utility, since the information
becomes partially redundant. Hence, priority is not a value defined inherently for each object in isolation, but rather is a function of relations between objects.

We simulate our camera network using the ONE (Opportunistic Network Environment) simulator and show that it achieves higher collection efficiency compared to traditional content-agnostic protocols in the presence of scarce resources. We also demonstrate an implementation of the service on a small number of phones (with pre-stored images of disaster scenes). Users will interact with both the simulator and the phones as detailed later in this document.

2. PHOTONET SERVICE OVERVIEW

All images managed by PhotoNet fall into a global naming structure similar to a UNIX directory tree. Content generated by sources has names that place it in one of the “directories.” For example, a rescue worker might take a picture, called ‘/rescue/pictures/volunteerA/pic1.jpg’. Queries are expressed in terms of content identifiers or prefixes, such as ‘/rescue/pictures’, that define a subtree in the global naming structure. The collection of content that belongs in that subtree is said to match the query. This collection is denoted by items(q) for a query q. Each query is associated with a sink node, to which results of the query are due. Figure 1 describes, at a conceptual level, data structures used by PhotoNet.

![Figure 1: PhotoNet architecture.](image)

A content-type-specific function, map(x), maps a data item, x, of a given type, into a fixed-length vector in the feature vector space. Namely, it extracts features of an image and its location for purposes of assessing similarity. Once content is mapped onto the high dimensional space, semantic similarity between items is simply reflected in distance between the associated points in space. Items that have similar content are closer in the feature vector space, whereas dissimilar objects lie farther apart. The location of items with respect to others in the feature space will determine their priority.

For a collection of data items, items(q), that matches a certain query, q, we need to measure how much similarity is present in the collection as a function of distances among the items in the feature vector space. For this purpose, we introduce the notion of quality of a collection of data items. Given a set I of n data items, its quality, denoted as Ψ(I), is computed as the average of squares of pairwise distances between all data items.

$$ \Psi(I) = \frac{\sum_{x,y \in I} \|x - y\|^2}{n \times (n - 1)} $$

(1)

Informally, Ψ(I) measures a level of diversity in the data set I. Data items that are farther from each other produce a larger Ψ(I), whereas data items that are clustered together produce a lower Ψ(I). To reduce semantic redundancy, the network should always make forwarding and dropping decisions that generate a higher Ψ(I) for a collection of data items, I. When a node in the network runs out of storage, content is dropped in an order that maximizes the quality of the remaining set. More formally, let the set of items stored locally at node X, that match query q, be called itemsX(q). Let the total space needed to store itemsX(q) be S\textsuperscript{total} and let the size of item x be denoted by S\textsubscript{x}. For each query, q, the next item to drop, x among those locally stored items that match the query, itemsX(q), is computed as follows:

$$ x = \max_{x \in \text{items}_X(q)} \frac{\Psi(\text{items}_X(q) - x)}{S\text{total} - S_x} $$

(2)

Forwarding packets to a different node upon an encounter is similar in that the sender must forward the item that maximizes the quality of the receiver’s data set. Since nodes do not know what items others have, they first exchange a summary of their data set, called pivots, computed by clustering their items then finding cluster centroids. Hence, a node forwards items that are maximally different from the receiver’s centroids first. We do not discuss noise issues in this demo. In general, to avoid forwarding anomalous outliers, the algorithm can be modified to require that items be corroborated first before they could be forwarded.

3. THE DEMONSTRATION SCRIPT

Users will interact with a simulator (of a large network) as well as with a small set of phones. A map will be shown of a city in distress, including the locations of trouble spots of which the rescue center needs to be informed. Simulated nodes, as well as phones, will “take pictures” (choose them from a pre-stored set of pictures associated with the location on the map that the node in question is at). PhotoNet, running both on phones and in the simulator, will attempt to deliver these messages to the rescue center. A scripted mobility pattern (not revealed to PhotoNet) will be used to determine when different nodes will meet and can exchange data. The set of pictures delivered to the rescue center will be shown on the screen as they get delivered. The locales they pertain to will be marked (on the map). Different routing and prioritization protocols will be compared to show visually how some of them cover more events quicker. The users will be allowed to change simulation parameters such as encounter length, bandwidth, content prioritization protocols, routing protocols, and the number of images generated. They will also be allowed to take pictures using the presented phones, to send to the rescue center.

4. REFERENCES
