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Quality of information-aware mobile applications[☆]

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A B S T R A C T

In this paper, we propose a framework for providing Quality of Information (QoI) aware networking. QoI quantifies how useful information is for a given application. Its value is comprised of both *intrinsic* and *contextual* attributes related to the information. Intrinsic attributes include freshness and accuracy of the information. Contextual metrics include completeness and timeliness. To design QoI-aware network control algorithms, such as resource control algorithms, attributes of data must be mapped to QoI. Then, network algorithms may deliver the data in such a way that the ultimate information derived from the data is of sufficient quality for its purpose. We propose our QoI framework, and present the concept of QoI functions that capture tradeoffs between different attributes of QoI. We use optical character recognition (OCR) as a model image processing application. We focus on two attributes of QoI for the OCR application: accuracy and timeliness. We show how network controls and data processing, such as error recovery and compression, operating on data, impact the QoI delivered to a recipient. We then show how reductions in the required QoI may have a drastic impact on the amount of network resources required to support a QoI-aware transaction. Our results are based on an implementation on Android phones.

1. Introduction

Resource allocation is critical for applications running on constrained networks. Unfortunately, data communication network resource allocation algorithms do not typically operate in an information-sensitive manner, but instead focus on the delivery characteristics of bits of data. We propose the notion of Quality of Information (QoI)-aware networking.

QoI is a composite, multi-dimensional measure that quantitatively and qualitatively identifies the degree to which data is suited for an application or a decision making process. Unlike Quality of Service (QoS), QoI considers both *intrinsic* and *contextual* aspects of information as discussed in Section 2. Intrinsic attributes include things like the age of information and its precision. Contextual attributes include things such as timeliness and completeness. QoI-aware networking algorithms must consider how data is transformed into information and the impact that the network may have on this transformation.

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As a simple example, consider a photo as a piece of information. The *intrinsic* attributes include freshness (age), the time that the photograph was taken. The *contextual* attributes include timeliness, which may be considered if the photo is being transferred across a network. In the case of a photo, timeliness may be improved by cropping or compressing. While we may instinctively think of these operations as degrading accuracy, this is not necessarily the case. For example, a photo with large amounts of unnecessary data may be cropped without affecting accuracy and a high-definition video may be compressed if the content of interest is sufficiently large and recognizable. These tradeoffs are made explicit in QoI-aware networking through the use of QoI-functions.

In this paper, we address the quality measure trade-offs in constrained communication networks for image applications. We use optical character recognition (OCR) as an example image processing application. We discuss QoI functions for this application to illustrate the trade-offs of different QoI attributes. We lay the foundation for a general model of QoI-aware networking to optimize information flow based on a comprehensive understanding of the information and the communication channels in use. As part of this, we map information quality attributes to data quality attributes, and determine the impact of the network on the delivered QoI. This model can be applied to information media other than images, such as video and audio.

In addition to the simulation results, we present experimental results from an Android mobile phone implementation. Because of the reliability of mobile wireless links, we consider Forward Error Correction in addition to various image transformations. Our results show that this QoI-aware approach allows more queries to be answered, faster, and with less network impact.

The rest of the paper is organized as follows: Section 2 details the QoI model. Section 3 describes our experimental setup and Section 4 presents results. Section 5 discusses related work and Section 6 concludes the paper.

2. QoI model

The QoI model we propose is applicable to both information at rest (stored) and information being retrieved, either in real-time or from storage. QoI is tied to the data used to generate the information and includes both intrinsic and contextual attributes as we discuss in detail below.

We define both a *requested QoI* and a *delivered QoI*. The requested QoI may be specified by the requestor as a vector of attributes, or a function that specifies the relationship (tradeoffs) between the different attributes. The delivered QoI is what is received by the requestor, perhaps after transfer across a network or after transformations have been performed on the information. The delivered QoI is stochastic because often the impact of transformations of data (for example compression) on information are not perfectly predictable; likewise, network conditions may vary and cannot always be accurately predicted.

In this work, we distinguish data from information. Information is derived from data. For example, if an image is used to determine the number of people in a room, the data is the image file and the information distilled from the data is the value of the number of people. Below, in general, we use the term information in our discussion. When data must be distinguished from information we do so explicitly.

2.1. QoI functions

QoI functions specify the relationship (tradeoffs) between different information attributes. The attributes are directly related to the information as it is being used by an application. The attributes can be classified as being either *intrinsic* or *contextual*. Intrinsic attributes are inherent in the information regardless of its use, for example the freshness of information, the bitrate of an audio sample or the resolution of a photograph. Contextual attributes depend on its use, for example the completeness or timeliness of information.

In general we can express the QoI as determined by an application as:

$$QoI_{\text{APP}} := f(attr_{\text{INTRINSIC}}, attr_{\text{CONTEXTUAL}}) \tag{1}$$

where $attr_{\text{INTRINSIC}}$ is a vector of the intrinsic quality attributes and $attr_{\text{CONTEXTUAL}}$ is a vector of the context-specific attributes.

The data delivered to an application has a certain fitness for use and can generate information of a certain quality. We call this measure the application score, S. For example, given an image of a face, a face recognition algorithm can match the face to a known person with an expected certainty. This certainty is the application score of the face detection algorithm.

Similarly, throughout this work we use OCR as an example application—the application score in this case is the degree to which an OCR application's output matches the actual document's contents. In both cases, however, additional factors, both intrinsic and contextual, impact the final quality of the information. For example, the information may be required within a certain time frame, thus imposing a contextual timeliness requirement. If it is received late it may not be as useful or of any use at all. We can therefore rewrite (1) for our example as:

$$QoI := f(S, A) \tag{2}$$

where S is the application score and A is the impact of other contextual and intrinsic attributes.

To evaluate QoI, one must consider the quality of *data* used by the application. Then, a mapping between data quality and information must take place. For example consider an OCR application: the accuracy of the OCR application is a function of