2019 57th Annual Allerton Conference on Communication, Control, and Computing (Allerton)
Allerton Park and Retreat Center
Monticello, IL, USA, September 24-27, 2019

Optimal Information Updating based on Value of Information

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I. Abstract

We address the problem of how to optimally schedule data packets over an unreliable channel in order to minimize the estimation error of a simple-to-implement remote linear estimator using a constant "Kalman" gain to track the state of a Gauss Markov process. The remote estimator receives time-stamped data packets which contain noisy observations of the process. Additionally, they also contain the information about the "quality" of the sensor/source, i.e., the variance of the observation noise that was used to generate the packet. In order to minimize the estimation error, the scheduler needs to use both while prioritizing packet transmissions. It is shown that a simple index rule that calculates the *value of information* (VoI) of each packet, and then schedules the packet with the largest current value of VoI, is optimal. The VoI of a packet decreases with its age, and increases with the precision of the source. Thus, we conclude that, for constant filter gains, a policy which minimizes the age of information does not necessarily maximize the estimator performance.

II. Introduction

There is a growing interest in providing real-time status updates in order to serve applications that depend upon the freshness of information available to them. For example, timely weather updates, stock prices information, Internet of Things devices, etc. Thus, the problem of ensuring timely status updates in real-time applications has received much attention [1], [2], [3]. The "Age of Information" (AoI), captures the freshness of the information that is available with the end application, and recent works have designed scheduling policies/ network controllers with the objective of minimizing the AoI in scenarios where multiple applications share a common network infrastructure. For example, more recently generated data packets are prioritized over older packets [4], or the packet of a user that currently has a larger value of age at the destination is prioritized over a user having smaller age, etc.

However, in many applications, it is not only the freshness of a packet that matters, but also the content that it contains. We will be interested in applications that generate an estimate of a process after receiving data packets that contain information about this process. Since the packets contain only noisy observations of the process, and not the "true" value of the process, it is also important that a packet which contains measurements that have a higher precision/low noise, must be prioritized over a packet that has the same age but has a lower precision measurement.

In summary, the quality of a packet is judged not only on the basis of how "fresh" the packet is, i.e., its age or the time since it was generated at the source, but it also depends upon the following two factors

1) How much information it contain about the process that is being monitored,
2) How important this information is to the algorithm that is being used to update the status at the destination node.

Regarding 1), we note that the information content in a packet is described by the joint probability distribution of its content and the true state/status of the process. In order for the factor 2) above to become crucial, it becomes important that the algorithm that is being deployed by the application uses the information contained in these packets efficiently.

In view of the above discussion, the following question arises naturally: How do we prioritize packets for scheduling in order to optimize the performance of such real-time systems? Should the packets be prioritized according to their age, or the noisiness of the observation contained in them, or a combination of both? In this work, we provide a concrete answer to this question when the process of interest that is being monitored by an application is Gauss Markov, while the algorithm that is being used to generate an estimate of the process is a simple-to-implement linear filter with a constant gain. We show that the optimal scheduler takes the following form: it attaches an index to each packet that is present in its queue, and then schedules the packet having the largest value of the index. This index depends upon the following two factors a) the age of the packet, b) the mutual information between the packet content, and the system status, or equivalently the variance of the noise associated with the measurement.

III. Related Works

Applications involving real-time systems such as the smart-grid, weather monitoring systems, etc., often require that the destination node, which comprises the end decision maker, has a constant availability of fresh *staus updates* about the process of interest. The age-of-information, or simply age, performance metric was introduced in [1], [5], [6], [7], and is an appropriate

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This material is based upon work partially supported by Office of Naval Research under Contract N00014-18-1-2048, the U.S. Army Research Office under Contract No. W911NF-18-10331, NSF under Science & Technology Center Grant CCF-0939370, and NSF Contract Nos. CNS-1719384, CCF-1619085, and ECCS-1646449.