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Context-aware end-to-end QoS diagnosis and quantitative guarantee based on Bayesian network

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Abstract

To support quality of service (QoS) management on current Internet working with best effort, we bring forth a systematic approach for end-to-end QoS diagnosis and quantitative guarantee. For QoS diagnosis, we take contexts of a service into consideration in a comprehensive way that is realized by exploiting causal relationships between a QoS metric and its contexts with the help of Bayesian network (BN) structure learning. Context discretization algorithm and node ordering algorithm are proposed to facilitate BN structure learning. The QoS metric is diagnosed to be causally related to its causal contexts, and the QoS metric can be quantitatively guaranteed by its causal contexts. For quantitative QoS guarantee, those causal relationships are first modeled quantitatively by BN parameter learning. Then, the QoS metric is guaranteed to certain value with a probability given its causal contexts tuned to suitable values, that is, quantitative QoS guarantee is reached. Simulations with three sequential stages: context discretization, QoS diagnosis and quantitative QoS guarantee, on a peer-to-peer (P2P) network, are discussed and our approach is validated to be effective.

Keywords context, context discretization, QoS qualitative diagnosis, QoS quantitative guarantee, Bayesian network

1 Introduction

Current Internet delivers services merely with its best efforts; QoS is only supported or guaranteed as much as possible. Here are some reasons for this awkward situation. First, it is not easy to trace, locate and identify the causes of a QoS violation on the volatile Internet. Second, even if this problem is fixed up, other problems may arise, for example, for security consideration, integrated service providers (ISP) are unwilling to open interfaces to customers or other ISPs to fine-tune or improve QoS. Third, not all hardware on current Internet can fully support QoS managements claimed in some protocols like DiffServ [1]. Besides, to support QoS managements, packets have to flow through more procedures, which will decrease the efficiency of these public facilities.

End-to-end QoS management is one way to overcome these problems since customers have full control of endpoints [2]; hence, parameters of these endpoints can be manipulated to support QoS management. In addition, end-to-end QoS managements do not force under layers to support QoS management; therefore, the efficiency of those public facilities will not be affected. Nowadays, overlay networks are widely used to meet the active demands for multimedia services and end-to-end QoS managements are claimed to be supported on those overlay networks. In this study, we will discuss two aspects of QoS management: QoS diagnosis and quantitative QoS guarantee, on a peer-to-peer overlay network.

QoS diagnosis is usually intended to identify QoS violations [3]. In our approach, we believe causal relationships lie between a QoS metric and its contexts [4] that this metric is residing in. In this study, we mainly deal with ‘soft’ contexts like the number of neighbors or buffer map ‘size’ of a peer in a P2P network, with respect to traditional ‘hard’ contexts such as temperature, location and so on. These contexts can be viewed as the causes of the QoS metric since the QoS metric changes along with these contexts. Naturally, we refer QoS diagnosis to identify these causal relationships between a QoS metric and its contexts. In this study, we employ BN to exploit these causal relationships as BN is intended for representing causal relationships [5].

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QoS guarantee tries to satisfy user's QoS requirements and to maintain a QoS metrics on certain level. When the causes of a QoS metric are qualitatively identified with QoS diagnosis, we will show that user's QoS requirements can be quantitatively fulfilled by tuning these causes or contexts to guarantee the QoS metric. This quantitative guarantee is facilitated by the quantitatively representation of BN for causal relationships.

In this study, we validate our approach on a P2P overlay network situation, and we would like to point out that our approach is applicable to more generalized situations or applications.

The remainder of this paper is arranged as follows: our approach will be illustrated in details in Sect. 2. Simulations and validations will be discussed in Sect. 3. A brief summary about related work will be given in Sect. 4. At last, in Sect. 5 we will make a conclusion about our approach.

2 Proposed approach

In general, QoS metric changes along with the contexts it resides in. For example, in a live streaming system mosaics will appear when packet loss rate (QoS metric) is becoming high, which is usually caused by network congestion (context). Network congestion in turn may be caused by some bandwidth greedy applications (context) e.g. BitTorrent (BT), whose packet transport protocol, e.g. user datagram protocol (UDP), may also be relevant to the QoS metric because no congestion control is built in UDP; as a result, bandwidth is preempted by UDP-based applications. Our approach takes all contexts into consideration in a comprehensive manner to exploit the causal relationships between these contexts and the QoS metric by QoS diagnosis. After that, contexts are tuned to guarantee user's requirements by QoS guarantee. Procedures of our approach are shown in Fig. 1.

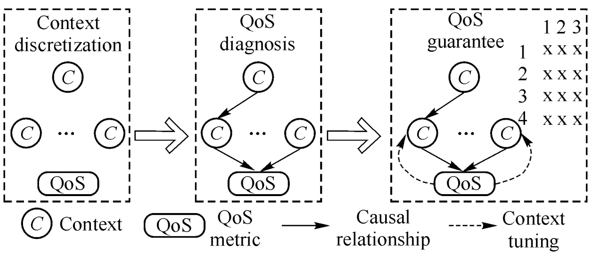

Fig. 1 Procedures of proposed approach

2.1 Context discretization

Context values may be continuous or discrete since they may have heterogeneous sources or come from different applications. Context values must be refined into discrete values to gain better generality because our approach are based on Bayesian networks and most BN toolkits like Bayes network toolbox (BNT) (Murphy K. Bayes Net Toolbox for Matlab. http://www.cs.ubc.ca/murphyk/Software/BNT/bnt.htm) support discrete inputs best.

Fuzzy set theory is one common way of mapping continuous values to discrete values [6]. A fuzzy set F is characterized by a membership function $f_F(x): X \to [0, 1]$, which associates each entity x (i.e. a snapshot or an instance of the continuous value) in its domain with a real number in interval $[0, 1]$, and $f_F(x)$ represents the grade of membership of x in F. Elements of the fuzzy set F are indistinguishable qualitatively, that is, they all belong to a same discrete output, although their grades of membership (i.e. the values of $f_F(x)$) may be different.

Once training data, a set of samples of a target context, is collected, Algorithm 1 is referred to make them discrete. Specifically, a continuous context is discretized into discrete one; a discrete context is reshaped to its expected form.

Algorithm 1 Context discretization algorithm

```
IN:    a sample set S_a of a target continuous context C
OUT:   a discrete value set DS of sample set S_a
  DS ← S_a;
 if the target context C is continuous then
     determine discrete value set 𝔻ℂ for C;
     for all element DC in 𝔻ℂ do
          determine membership function f_DC(c) of DC
     end for
     for all element s in S_a do
        find membership function f_DC(s) with the largest value;
        s is discretized as discrete value DC;
        replace s with DC in DS;
    end for
 else{/*if the target context C is discrete*/ }
    for all discrete sample s in S_a do
        refine s into expected form DC
        replace s with DC in DS
    end for
 end if
 return DS
```

2.2 Qualitative QoS diagnosis

After contexts are in their right form, QoS diagnosis is