Available online at www.sciencedirect.com
ScienceDirect
Computer Communications 31 (2008) 1497–1512
computer communications
www.elsevier.com/locate/comcom

Link quality prediction in mesh networks

Károly Farkas [a,*], Theus Hossmann [b], Franck Legendre [b], Bernhard Plattner [b], Sajal K. Das [c]

[a] Institute of Informatics and Economics, University of West Hungary, Bajcsy-Zsilinszky u. 9., H-9400 Sopron, Hungary
[b] Computer Engineering and Networks Laboratory (TIK), ETH Zurich, Gloriastr. 35, CH-8092 Zurich, Switzerland
[c] Center for Research in Wireless Mobility and Networking (CReWMaN), The University of Texas at Arlington, TX 76019, USA

Available online 2 February 2008

Abstract

Wireless self-organizing networks such as mesh networks strive hard to get rid of mobility and radio propagation effects. Links – the basic elements ensuring connectivity in wireless networks – are impacted first from them. But what happens if one could mitigate these effects by forecasting the links' future states?

In this paper, we propose XCoPred (using Cross-Correlation to Predict), a pattern matching based scheme to predict link quality variations. XCoPred does not require the use of any external hardware, it relies simply on Signal to Noise Ratio (SNR) measurements (that can be obtained from any wireless interface) as a quality measure. The nodes monitor and store the links' SNR values to their neighbors in order to obtain a time series of SNR measurements. When a prediction on the future state of a link is required, the node looks for similar SNR patterns to the current situation in the past (time series) using a cross-correlation function. The matches found are then used as a base for the prediction. Clearly, XCoPred takes advantage of the occurrence and recurrence of patterns observed in SNR measures reflecting the joint effect of human motion and radio propagation. XCoPred focuses only on the scale of links and as such is complementary to mobility prediction schemes, which target prediction at a broader scale. We first prove the occurrence of SNR patterns resulted by the joint effect of human motion and radio propagation. Then we evaluate XCoPred in an indoor mesh network showing, that XCoPred is able to recognize mobility patterns in up to 85% of the cases correctly and the average prediction error on mid-term predictions (i.e., assessing the future link quality more than 1 min ahead) is less than half the error we get using linear prediction.

Eventually, we propose and evaluate an enhanced handoff management scheme for 802.11 mesh networks showing the usefulness of XCoPred as a cross-layer input.

Keywords: Link quality prediction; Mesh networks; XCoPred; Kalman filter; Pattern matching

1. Introduction

Self-organizing networks such as mesh networks pose significant challenges on the design of new communication protocols and applications. One important aspect to deal with is the joint effect of node mobility and radio propagation, and their consequences [1]. Even though recent works have contributed to demonstrate their benefits for different network aspects such as increasing capacity [2], security [3], and coverage [4], just to cite a few, still mobility and radio propagation have a great impact on every layer of the protocol stack. What happens if we could mitigate or, in other words, we could forecast their effect? Many solutions have been proposed to predict macroscopic mobility, i.e., the sequence of base stations or access points encountered by a node, which are useful for handoff, resource reservation or route selection in fixed cellular and self-organized mesh networks. Yet, our goal is not to predict macroscopic mobility, but instead predict the rather short term (i.e. tens of seconds) variations of link quality. This is important as links are in fact the basic elements ensuring connectivity in self-organized networks and having a precise view on the future evolution of a link is fundamental for applications

* Corresponding author. Tel.: +36 30 9843449.
E-mail addresses: farkas@inf.nyme.hu (K. Farkas), hossmath@tik.ee.ethz.ch (T. Hossmann), legendre@tik.ee.ethz.ch (F. Legendre), plattner@tik.ee.ethz.ch (B. Plattner), das@cse.uta.edu (S.K. Das).

0140-3664/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2008.01.047

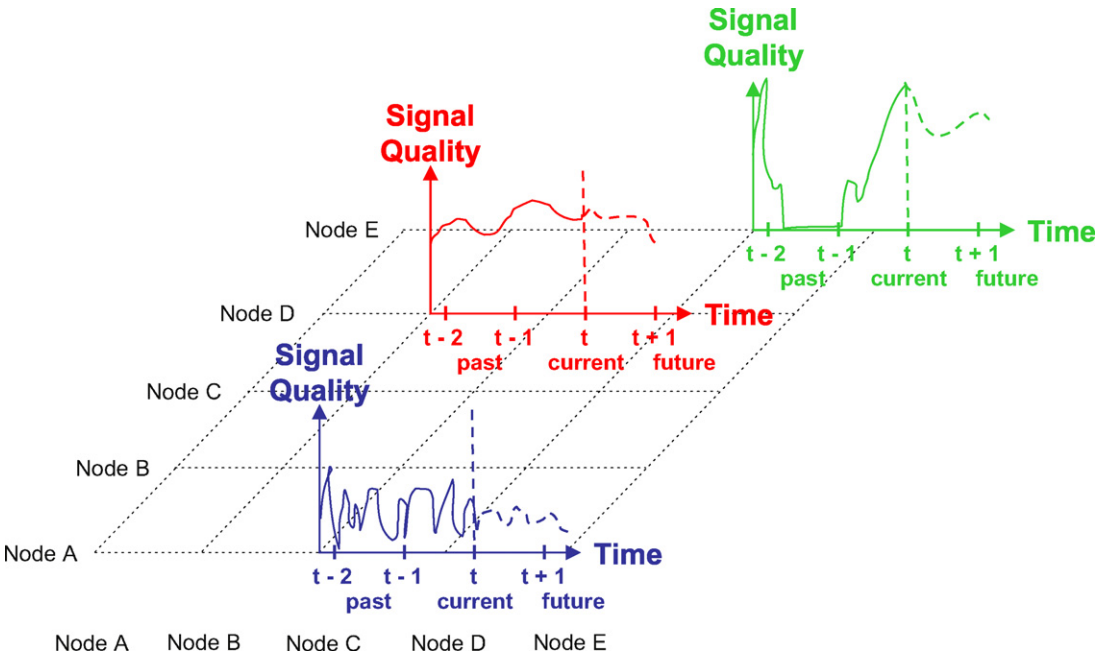

Fig. 1. Signal quality past time series (solid lines) and its predicted future variations (dashed lines).

at all layers of the protocol stack to optimize, or increase the reliability of these networks. However, current prediction schemes on links provide assessments only with a coarse precision in space and time, thus the applicability of these approaches is limited.

In this paper, we propose XCoPred (using Cross-Correlation to Predict), an approach based on pattern matching, to predict a link's future state in terms of its quality variations. XCoPred does not consider possible emerging links in the future (i.e., link creation) but performs predictions on a node's existing links to its neighbors. We present here an enhanced version of XCoPred that was first described in [5]. In contrast to most of the existing prediction techniques targeting node mobility like [6–8], XCoPred does not require the use of any external hardware or reference points. Each node monitors and stores the signal quality of its links to obtain a time series of link quality measures (cf. Fig. 1 which illustrates this with a hypothetical network consisting of five nodes). The Signal to Noise Ratio (SNR) is used as this measure. When a prediction is required, a node searches patterns similar to the current situation in the history of its stored time series of link quality measures. For this purpose, the node computes the normalized cross-correlation between the current pattern and the history of the links' quality. Several matches may be found and the one with the highest cross-correlation value is retained. Otherwise, XCoPred applies a fallback solution based on autoregression.

Clearly, XCoPred takes profit of the occurrence and repeatability of patterns seen at the scale of links. In order to validate our approach, we prove the existence of patterns in the joint effect of human motion and radio propagation (at the scale of links) with the example of indoor pedestrian motion, and its reflection in the signal space. We evaluate the performance of XCoPred by experiments using SNR measurements from a real indoor mesh testbed with a static backbone of 20 nodes and mobile, handheld devices carried by human-beings. Results show, that using the cross-correlation XCoPred is able to recognize mobility patterns in the SNR measurements in up to 85% of the cases correctly and that the average SNR prediction error of 3 dB for predicting the 60 s ahead future of the links is less than half the error we get using linear prediction.

Although XCoPred was designed to deal with link quality changes occurred by node mobility but the backbone nodes in a mesh network are usually static, still we can exploit the power of our approach in such networks targeting mobile end devices and their handoff. Thus, we propose and evaluate the use of XCoPred's predictions for improving handovers of mobile devices between access points in 802.11 mesh networks.

We can summarize the novelty and contributions presented in this paper as follows:

- We consider the problem of predicting link quality variations in mesh networks.
- We propose XCoPred, a pattern matching based approach for predicting future link quality.
- XCoPred does not require the use of any external hardware or localization scheme. Rather it relies for its prediction on link quality measures obtained from off-the-shelf 802.11 wireless cards (i.e., Signal to Noise Ratio (SNR)).