Poster Abstract: Achieving Stable Network Performance for Wireless Sensor Networks

Shan Lin, Gang Zhou†, Yafeng Wu, Kamin Whitehouse, John A. Stankovic, and Tian He‡
Department of Computer Science, University of Virginia, Charlottesville, VA
†Department of Computer Science, College of William & Mary, Williamsburg, VA
‡Department of Computer Science and Engineering, University of Minnesota, Minneapolis, MN
{sl8yc,yw5s,whitehouse,stankovic}@cs.virginia.edu †gzhou@cs.wm.edu ‡tianhe@cs.umn.edu

ABSTRACT

Extensive empirical results reveal that interference can cause link qualities to change quickly and dramatically. For such highly dynamic links, the short term link quality estimations widely used in existing protocols require frequent measurements and may not be accurate. As a result, when these links are selected, end-to-end communication quality varies significantly. Also, route changes occur frequently, introducing traffic oscillation and excessive overhead in network protocols. To achieve good and stable network performance, it is not enough to use short term link estimation. It is essential to characterize a link's capacity to perform well at a desired level in the presence of interference and environmental changes. Therefore, we propose a performance metric called *competence*. We have incorporated the competence metric into routing algorithm designs. We have also designed and implemented a maintenance framework that stabilizes performance at both link and network layers. This framework allocates the desired performance level among multiple links along an active route by using an end-to-end feedback loop, and enforces the performance level of each link through adaptive transmission power control and retransmission control. In real system evaluations with 48 T-Motes, our solution outperforms previous protocols significantly and achieves end-to-end stable performance for more than 99% of the time over 24 hours.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*wireless communication*

General Terms

Algorithms, Design, Measurement, Performance

Keywords

Stable Performance, Interference, Wireless Sensor Network, Feedback Control

1. INTRODUCTION

Extensive empirical results reveal that communication qualities of certain wireless links are highly unstable in dynamic environments. Their link qualities change quickly and dramatically due to interference. We identify that a cause for such high dynamic communication quality is human-related activities, such as people walking around and using wireless devices (Wi-Fi), as shown in Figure 1. Unfortunately, the short term link quality estimations widely used in the existing protocols of wireless sensor networks [1] [2] [3] require frequent measurements and may not be accurate. As a result, when these unstable links are selected, network performance varies significantly in terms of the end-to-end packet delivery ratio (PDR) and latency. Also, route changes occur frequently, introducing traffic oscillation and excessive overhead in network protocols.

Researchers have proposed many link estimation techniques for low-quality and time-varying links, but research on link characterization in wireless sensor networks is limited. Link characterization is complamentary to link estimation, describing a link's property, such as stability. To fill in this missing gap, we propose *competence* as a performance metric for wireless sensor networks. Intuitively, if a performance measurement such as packet delivery ratio stays at a desired level in the presence of interference, the quality of this performance measurement is competent. Based on this competence metric, we propose routing algorithms to choose competent routes and a maintenance framework that adaptively stabilizes performance at a desired level. Our design goal is to provide stable end-to-end network performance, reducing overhead and network oscillation.

2. DESIGN OVERVIEW

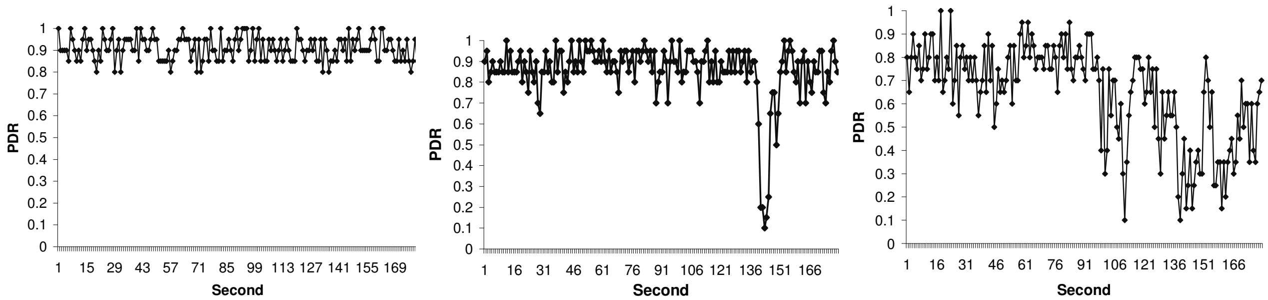
Based on our experimental observations, we propose a competence metric to quantify how well a signal performs at a specified level. This signal can be any network performance measure, such as PDR and latency. The requirements for this network performance measure are specified as bounds on the signal. A signal is competent if it is bounded over time. Take PDR as an example. The PDR is competent if its value is within a specified quality range. We formally define competence metric $c(t)$ in Equation 1.

$$c(t) = \alpha \cdot c(t-1) + (1-\alpha) \cdot s \ , \quad 1 > \alpha > 0 \qquad (1)$$

$$s = \begin{cases} 1 & if \ \ Y(t) \in [T_{lower}, T_{upper}] \\ 0 & otherwise \end{cases}$$

Based on the competence metric, we design an competence enhanced routing protocol. The key idea for competence enhanced routing is to choose competent links. Selecting competent links has two benefits: first, the end-to-

SenSys'08, November 5–7, 2008, Raleigh, North Carolina, USA.
ACM 978-1-59593-990-6/08/11.



(a) Night: Radio Signal Fading (b) Day: People Walking Around (c) Day: People Using Wi-Fi

Figure 1: Link Quality Variation under Different Interference Sources

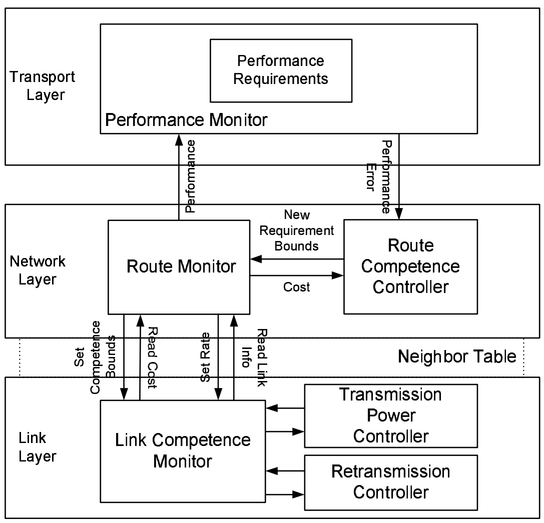


Figure 2: Control Architecture

end performance meets the specified requirement better, this is because every link along a path is chosen according to the specified performance level; second, choosing competent links reduces traffic oscillation and energy consumption, this is because that the competence metric tolerates small variations as specified by the bounds, but reacts to big variations via parent switches.

We also design a maintenance framework. This framework assigns and maintains different requirements on different links. We note that a specified link quality can be maintained with the cost of retransmissions and transmission power control. For those competent links, high and stable performance can be achieved with a small cost. While for the other links, maintaining a relative good performance can be costly. So we design a distributed algorithm for link competence assignments along a path to meet an end-to-end performance level and optimize total energy consumption. Figure 2 shows our control based design. The performance monitor, competence controller, and route monitor form an end-to-end control loop. The performance monitor and competence controller are located on the sink node, while the route monitor is located on each node along a path. A control packet is relayed to collect local cost by the route monitor from the source node to the sink node. The performance monitor compares the end-to-end performance competence with the specified performance requirement. If there is an error, it notifies the competence controller. The competence controller takes the performance error and collected cost as inputs, and calculates the competence requirement for each link along this path. Another control packet is sent from sink to source, assigning new link level requirements to each route monitor. Those link competence requirements are enforced by transmission power control and retransmission control.

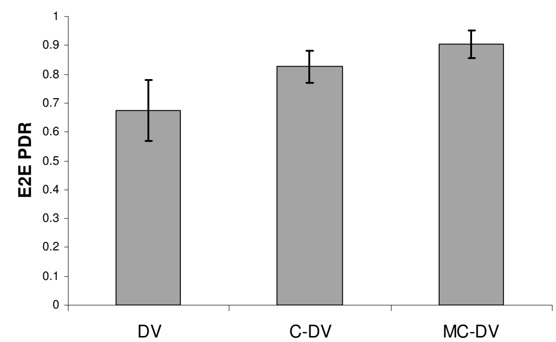


Figure 3: Average E2E PDR

3. EVALUATION

We have implemented a competence routing algorithm and a maintenance framework on TinyOS 1.x. In the experiments, we compared a DV routing, a competence enhanced DV routing (C-DV), and a competence enhanced and maintained DV routing protocol (MC-DV). Our experimental results on a 48 motes wireless test-bed demonstrate: first, that using our competence metric improves routing performance significantly. As shown in Figure 3, with specified requirement bounds [80%, 100%], the average end-to-end PDR of C-DV is above 80% for more than 80% of the time. The average end-to-end PDR of MC-DV is above 80% for over 99% of the time. Second, our design is more energy-efficient with highly dynamic link qualities. C-DV improves energy efficiency over DV by around 15%. MC-DV improves energy efficiency over DV by around 17%. In MC-DV, extra control packets cost a very small amount of energy.

4. REFERENCES

[1] "IEEE 802.15.4, Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs)," 1999.

[2] A. Woo, T. Tong, and D. Culler, "Taming the Underlying Challenges of Reliable Multihop Routing in Sensor Networks," in *ACM SenSys*, November 2003.

[3] R. Fonseca, O. Gnawali, K. Jamieson, and P. Levis, "Four bit wireless link estimation," in *Sixth Workshop on Hot Topics in Networks (HotNets VI)*, 2007.